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ORDINARY MEETING.

3 December, 1935.

Mr. JOHN DUNCAN WATSON, President, in the Chair.

On the motion of the President, it was resolved :—

"That the members of The Institution desire to record the deep regret with which they have learned of the death of The Right Honourable Earl Jellicoe of Scapa, G.C.B., O.M., G.C.V.O., Admiral of the Fleet, whom they elected as an Honorary Member in January, 1919, in recognition of the great services which he had rendered to the Empire during the War.

"They also desire to express their sincere sympathy with the members of his family in their bereavement."

The Council reported that they had recently transferred to the class of

Members.

William Bentley.
Charles Eric Boast, M.C.
James Gibson Cuthbert.
Basil Proockter Fletcher.
Ernest John Goodacre.
John Alexander King Hamilton, B.Sc. (*Edin.*).
Ernest Edward Lee Vincent.
George William Williamson, O.B.E., M.C.

And had admitted as

Students.

Raymond Langford Akers.
Ronald William Allport.
Ronald Ewart Annetts.
Richard Henry Arnold.
Deryck Walter Ault.
Arnold Bailey.
Harold William Baldwin.
Arthur Liddell Ballantyne.
Robert Harold Barnett.
Thomas George Batchelar.
Edward Bates.
Angus Brunel Beaton.
Kenneth Matthew Beer.
Anthony Steele Bertlin.
Purushottam Ramachandra Bhide, B.E. (*Bombay*).
Arthur Joseph Bishop.
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Alexander Bruce Bridger.

Bertram Marsdin Bridges.
Hamilton Bruce.
George Edward Bullough, B. Eng. (*Liverpool*).
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Donald Hubert Campbell.
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John Forbes Glennie, B.Sc. (*Bristol*).
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John Ridley Gunn.
David Osborne Hall.
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Ernest Harold Sidwell.
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John Warner.
Paul St. Claire Webber.
Richard Sidney Wesson.
James Maurice Whitaker.
Frank Bruce White.
John Edmund Gifford Whittome.
Bernard Wilkinson.
Leslie Graham Williams.
Stephen Brian Weir Williams, B.Sc. (Eng.) (*Lond.*).
Howard Frederick Yeomans.

The Scrutineers reported that the following had been duly elected as

Member.

Sir Frank Robert Simpson, Bart.

Associate Members.

Albert Miller Alberga, B.Sc. (*McGill*).
Cyril John Snowden Appleyard, B.Sc. (*Leeds*).
Christopher Francis Armstrong.
Sanmugam Arumugam, B.Sc. (Eng.) (*Lond.*).
Frank Stuart Atkinson, M. Eng. (*Sheffield*).
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William Eric Haigh (Stud. Inst. C.E.).
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Percy Hall, B.Sc. (Eng.) (*Lond.*).
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Charles Alfred Percival Hart, B.Sc. (Eng.) (*Lond.*).
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George Branson Hetherington, B.E. (*Sydney*).
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Stanley Walters Hickin (Stud. Inst. C.E.).
Raymond Hillier, B.Sc. (Eng.) (*Lond.*) (Stud. Inst. C.E.).
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Jal Rustomji Kanga, B.E. (*Bombay*).
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William Frederick Longfield.
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Andrew Louis Wilson, B.Sc. (*Belfast*).
Robert Kinnear Wood.
Alfred John Wynne (Stud. Inst. C.E.).
William Young.
William Young, B.Sc. (*Glas.*).

Associates.

Kenneth Gray.
Henry Erskine Seymour Bryant Irvine, B.A. (*Oxon.*).

The following Paper was submitted for discussion, and, on the motion of the President, the thanks of The Institution were accorded to the Author.

Paper No. 5031.

"The Energy-Output of the Coal-Miner."

By Professor Kenneth Neville Moss, O.B.E., M.Sc., Assoc. M. Inst. C.E.

TABLE OF CONTENTS.

Engineers have often to take responsibility for large undertakings which depend to a great extent on manual labour, and if the men are of poor physique, the estimated costs may be affected seriously and the quality of the work may suffer. It is frequently not realized that this may not always be the fault of the men, but may often be due to an inadequate supply of food; sufficient food alone makes possible a sustained output of hard manual work. The result of the Author's researches in connection with the energy-output and the food-requirements of the coal-miner will, it is hoped, be of interest to members of this Institution, because the results, in principle, are of general application. Some years ago the Author determined the calorific value of the food actually consumed by sixty coal-miners for periods of from 7 to 10 days, the results being summarized in Table I.

The most interesting feature of the data thus obtained is that the food-consumption varies with the temperature of the working-places. The higher the air-temperature below ground the more food appears to be required. The reason for this is not wholly understood, but one aspect of the problem will be discussed later. It will be seen that a coal-miner needs a good deal of food, much more in fact than is allowed by some dietitians with no practical knowledge of mining.

The Relation of Energy-Output to Food-Requirements.—Having determined the energy put into the body by the food, it is of interest to determine the energy-output to see whether there is a real basis for the relatively high food-consumption. It is not possible to determine the energy-output over a 24-hour period, but

TABLE I.

District.	No. of forms returned.	Average period covered by each form: days.	Average underground temperature: ° F.	Month of year in which forms were filled up.	Average height of the men: centimetres.	Average weight of the men: kilograms.	Average body surface: square metres.	Average calorie value of food eaten per man per day.	Calories per square metre of body-surface.	Wages standard on the basis of the highest.	Average total liquid drunk per day: pints.
Pendleton	6	10	99	May	172	62·7	1·75	5925	3386	82	11·9
Pendlebury	6	10	88	July	168	60·4	1·68	5114	3044	82	9·2
Hamstead	10	9·1	79	June–Sept.	170	70·0	1·81	4644	2566	80	8·5
Forest of Dean	12	7·2	68	Dec.–Jan.	169	63·1	1·72	4293	2494	55	3·6
Derbyshire	8	10	66	March	169	59·9	1·69	4211	2491	100	4·4
Yorkshire	8	7·6	59	Feb.–July	169	65·0	1·75	4472	2555	90	4·6
SouthWales	10	7·9	55	Dec.–Jan.	170	65·3	1·76	4320	2454	88	3·7
Mean figures for the whole							1·74	4711	2713	—	6·55

if it can be determined during working-hours, the energy-output for the remaining portion of the 24 hours may be estimated with a fair degree of accuracy. Before describing the experimental method used to determine the energy-output during work, it is necessary to deal very briefly with the physiology of the subject.

The production of heat inside the body is due to the metabolism of the food which has been digested. The metabolic processes may be likened thermo-dynamically to the burning of fuel in a locomotive; the greater the work done, the greater is the amount of food required and the larger is the volume of oxygen needed for its combustion. It is a well-known physiological law that the energy expended during work exactly equals the energy set free by metabolism. Thus, if the volume of oxygen taken in by the body can be determined accurately, the heat produced can be calculated to a fair degree of accuracy on the assumption that the oxidation of food inside the body produces 5 kilogram-calories for every litre of oxygen consumed. Again, 1 Calorie is equivalent to 3,086 foot-pounds of energy. The energy generated in the body is nearly all transformed

into heat, which is mainly dissipated at its surface; during severe muscular work the heat produced may be ten times that produced while the body is at rest.

The experimental method employed to determine the energy-output of a man consists in making him breathe air through a rubber mouth-piece and a corrugated rubber tube, which has a meter and a two-way tap in the circuit. If the temperature, humidity and pressure of the intake air be determined, the volume breathed, as shown by the meter over a given interval of time, can now be calculated on a dry basis at normal temperature and pressure. If, in addition, samples are taken of the inspiratory and expiratory air, their analyses show all the data necessary for determining the oxygen intake by the body. The apparatus used is shown in *Fig. 1*. A 6-foot length of corrugated rubber tubing is attached to the meter, which records the volume of air breathed to the nearest hundredth part of a litre, and this in turn is attached to a mouth-piece with inspiratory and expiratory valves. On the expiratory side of the mouth-piece is attached another 6-foot length of corrugated rubber tubing, which has at its end a special connection with a two-way cock. When it is desired to take a sample of the expiratory air, a "Douglas" bag of 100 litres capacity is attached to the two-way cock, and the expired air passes out to the atmosphere until the sample is about to be taken, when the tap is turned to allow it to pass into the bag. The expired air is allowed to flow into the "Douglas" bag for 1, 2, or 3 minutes, according to the rate at which it fills, and then, the contents having been well mixed, a sample is driven through a large sampling tube by exerting pressure on the walls of the bag. A nose-clip is placed on the man to force him to breathe entirely through the mouth. In all the Author's investigations only men who were in training as members of rescue-teams were employed, because, being accustomed to wearing breathing apparatus, they were in no way distressed by this artificial restriction of their freedom of breathing.

The data obtained whilst experimenting upon an individual man were set out in the manner shown in Table II.

It will be seen that it is now possible, when the results of the air analyses are known, to determine the oxygen-intake in litres during a reasonable portion (as determined by the sampling time) of the time spent on each specific part of a miner's work.

In order to estimate the approximate work-output, each man on whom experiments were performed in the mine came to the University to enable additional data to be procured. On this occasion his height and weight when stripped were obtained. He was then made to pedal a cycle-ergometer and his oxygen-intake for four or five different work-outputs was determined. Usually a straight-line

Fig. 1.

APPARATUS FOR THE DETERMINATION OF THE ENERGY-OUTPUT OF A COAL-MINER.

TABLE II.

Time.	Occupation.	Remarks.
7.30		Entered working place. The man was connected to air meter. Barometer 31·45 inches. Dry bulb temperature 74° F. Wet bulb temperature 65° F.
7.32	Commenced to cut coal.	Inspired air sample No. 1 taken.
7.40	Cutting coal.	Expiratory air sample No. 1 taken over a 3-minute period.
7.50	,, ,,	Expiratory air sample No. 2 taken over a 3-minute period.
7.55	Commenced loading coal into wagon.	
8.5	Loading coal.	Expiratory air sample No. 3 taken over a 2-minute period.
8.15	,, ,,	Expiratory air sample No. 4 taken over a 2-minute period.
8.20	Commenced to cut timber with an axe.	
8.25	Cutting timber.	Expiratory air sample No. 5 taken over a 3-minute period.
8.29	,, ,,	Inspired air sample No. 2 taken.
8.30	Commenced to erect timber props to support roof.	
8.33	Erecting timber.	Expiratory air sample No. 6 taken over a 2-minute period.
8.35	Commenced to rest.	
8.38	Resting.	Expiratory air sample No. 7 taken over a 3-minute period.
8.45	Commenced to cut coal.	Barometer and temperature same as recorded above.
Etc.	Etc.	Etc.

graph was obtained, and from it the work-output in the pit could be estimated roughly by reading from the graph the work-output in foot-pounds per minute corresponding to the oxygen-intake during pit-work.

It has always been assumed that the mechanical efficiency of a miner's work is in the region of 25 per cent., but recent experiments which have been carried out by the Author have shown this to be a fallacy. If a miner always worked in an erect position then the assumption of 25 per cent. efficiency would be approximately correct, but a miner does most of his work in a stooping position. In the light of data recently obtained it appears that a miner's actual work-output, even under the most favourable conditions, is only about 15 per cent. of his total expenditure of energy.

TABLE III.

Name of man.	Height of man: inches.	Weight of man: pounds.	Area of body: square metres.	Working shift in stall: minutes.	Occupation.	Time spent on each occupation.		Average volume of air breathed: litres per minute.	Oxygen consumption.		Energy set free by metabolism: foot-pounds per minute.	Work output from ergometer-graph: foot-pounds per minute.
						Minutes.	Percentage of shift.		Average: cubic centimetres per minute.	Time over which average was taken: minutes.		
A.B.	72·5	185·5	2·07	407	Resting.	92·0	22·6	17·07	777·2	25·0	7,780	—
					Getting Coal.	177·5	43·6	34·45	1,800	62·0	23,570	4,160
					Loading.	48·8	12·0	33·15	1,914	178·0	25,320	4,450
					Timbering.	21·3	5·2	23·79	1,717	3·3	22,270	3,935
					Drilling a shot-hole.	23·5	5·8	33·84	1,958	16·5	26,000	4,590

Actual work done by a miner has, however, no significance in relation to his food-requirements. Finally, the results for each man were summarized in the manner shown in Table III.

In this manner the data for twelve different men were obtained. When the results were summarized and averaged, it was found that the time spent in the working place during the shift was 326 minutes excluding meal-time, and the consumption of oxygen during this period was at the rate of 1,333 cubic centimetres per minute, which, after deducting the average oxygen basal resting rate,[1] was equivalent to 16,950 foot-pounds per minute. This energy-output is equivalent to walking in an erect position at 3·7 miles per hour on the level. The work-output can be estimated roughly on the assumption of a body mechanical efficiency of 15 per cent., and is 2,542 foot-pounds per minute, or about 828,700 foot-pounds during the time spent in the stall, which was approximately 5½ hours.

A rough estimate of the total energy-output for a whole day may now be obtained, since an intake of 1,333 cubic centimetres of oxygen per minute is equal, on the basis of 5 kilogram-calories per litre, to 6·66 Calories per minute. The daily energy-output is therefore calculated in the manner shown in Table IV.

TABLE IV.—AVERAGE DAILY OUTPUT OF MINERS.

Occupation.	Calorie basis of work per hour.	Time in hours.	Calories.
Work in pit, allowing 30 minutes for meal-time	400	7½	2,800
Walking to and from pit (above ground) at 3 miles per hour	300	1	300
Leisure hours = Basal rate + 60 per cent. = (39·7 × 1·78) + 60 per cent.	113	7½	850
Sleeping hours = Basal rate − 5 per cent. = 70·6 − 5 per cent. . . .	67	8	540
Total . .		24	4,490

The output of energy at the coal-face was found to be at the rate of 6·66 Calories per minute for 5½ hours. The shift below ground was, however, 7½ hours, the balance of time being occupied in walking between the pit bottom and the coal-face, and *vice versa*, and in the meal-time, for which 30 minutes was allowed. The energy-

[1] Basal rate is 0·132 litres per minute per square metre of body-surface.

output whilst walking can be regarded as of the same order as for the working period, and hence, ignoring the 30 minutes allowed for the meal-time, the energy-output below ground can be estimated at 400 Calories per hour for 7 hours.

The intake of oxygen during sleep in bed is usually taken as from 10 to 15 per cent. below the basal rate, but as miners usually eat a large meal immediately before retiring for the night, the figure of basal-rate less 5 per cent. has been adopted.

Since the energy-output of a miner is approximately 4,500 Calories per day, it is clear that the calorific value of his food-input must be in excess of this to allow for waste. Hence, from 4,750 to 5,000 Calories per day are needed in the form of food. Should the calorific value of the miner's food be seriously reduced, it is clear that his work-output will fall equally seriously.

The Effect of Working in a Constrained Position.—Experiments were carried out in the University by the Author, in order to determine the effect on the energy-output of a collier when walking in a constrained position along low roadways at 3½ miles per hour. The positions chosen were :—

(1) The erect position.

(2) The half-stoop, corresponding to a loss of body height of 20 per cent.

(3) The full stoop, corresponding to a loss of height of 40 per cent.

(4) The all-fours position, equal to a loss of height of 50 per cent.

It was found, taking the average for eight men, that the percentage increases in the energy-output for the stooping positions over the normal walking position were :—

Half-stoop = 20·6 per cent. Maximum 29·5 per cent. Minimum 10·2 per cent.

Full stoop = 65·1 per cent. Maximum 96·0 per cent. Minimum 49·0 per cent.

All fours = 72·8 per cent. Maximum 90·4 per cent. Minimum 60·0 per cent.

This shows very clearly the disadvantage of low roadways underground and the great falling off in the mechanical efficiency of the body when working in a constrained position.

Before passing to an entirely different aspect of the subject, it is necessary to point out that data collected in the form of Table II will give reliable information concerning the time spent upon useful productive work and the time occupied in resting. In a recent time-study of one hundred coal-face workers, the Author has shown that the average resting time during the shift was 25·2

per cent., and since 6·9 per cent. was occupied in eating, only 67·9 per cent. of the working-shift was available for actual work.

The Effect of Working in High Air-Temperatures.—At an earlier stage of this Paper reference is made to the increase in the consumption of food when men have to work under conditions of high air-temperature. It is necessary to discuss one very important aspect of this fact.

A man who is doing hard manual work generates a good deal of heat, and his body-temperature will rise if this is not dissipated. Generally speaking, normal body-temperature is maintained by a constant balancing of the production of heat in the body against the loss of heat from its surface and from the respiratory tract. During hard work, the normal process of losing heat by radiation and convection is totally inadequate, and therefore the body makes use of the latent heat of evaporation of water, which is produced by sweating, in order to absorb the bulk of the heat generated. Thus the evaporation of sweat from the surface of the skin is mainly responsible for keeping the temperature of the body normal during hard work in a warm atmosphere. The amount of sweat lost by the body during work may be very considerable, as will be seen from Table V, which summarizes the results of the Author's investigations carried out some years ago at a colliery in Lancashire.

TABLE V.

Name of Colliery.	Underground temperature.	Case No.	Number of experiments on each case.	Maximum loss per shift: pounds.	Minimum loss per shift: pounds.	Average loss by sweating during a shift: pounds per hour.
Pendleton .	98–100° F. dry, 85° F. wet.	1	2	18·56	15·25	3·175
		2	2	18·75	18·00	3·145
		3	2	16·12	15·44	2·695
		4	2	17·12	11·81	2·670
		5	2	13·68	12·75	2·475
		6	2	12·44	12·12	2·280
		7	2	12·68	10·81	2·205
		8	2	12·12	11·31	2·185
		9	2	12·94	10·44	2·168
		10	2	13·75	9·68	2·160
		11	2	13·25	11·62	2·135
		12	2	10·56	10·12	1·930
		13	2	9·37	9·31	1·760

It will be seen that the maximum loss by sweating was 18·75 pounds during one shift. If a miner at work in a pit does work which produces, by metabolism, a heat output of 2,800 kilogram-calories, including the energy spent in walking from and to the pit bottom, then the evaporation of water from the skin and respiratory tract that is necessary to neutralize this heat production will be $\frac{2,800}{582}$, equal to 5·8 litres or 10·6 pounds.

Some miners lose much more sweat than is necessary because the sweat glands release it so quickly that it trickles down the body and does not evaporate completely.

In order that men working in high air-temperatures can sweat at a rate high enough to neutralize the heat production within the body, it is necessary that they should drink sufficient water or other liquid during the day. When the air is cold, the loss of heat by conduction and radiation will be greater, and therefore there will be less evaporation from the skin.

Since the normal body-temperature is about 98·6° F., it follows that no heat-loss by evaporation can take place if the wet-bulb temperature of the air reaches this figure. A man attempting to work under such conditions would very quickly get a heat-stroke. Thus, in order that a man may be able to work satisfactorily, the wet-bulb temperature of the air must be kept well below that of the body-temperature, preferably not higher than about 85° F., and the air must be kept in motion in order to prevent heat stagnation in the air and/or clothing surrounding him. Acclimatization plays a very important part in enabling a man to work comfortably in high air-temperatures. If a man unaccustomed to high temperatures were made to work hard in an air-temperature of 100° F. he would certainly run a grave risk of getting a heat-stroke. Miners, however, can carry on for years without any detriment to their health, provided that, when they first begin work in a hot pit, they take a month or more to get acclimatized to the abnormally high air-temperature conditions.

The necessity for men who work in hot places to drink much liquid will be appreciated. If, however, the temperature is high and the air contains a good deal of dust, the miner's throat is liable to get dry and he is therefore tempted to drink much more water than is necessary in order to allay the parched feeling in the throat. Apart, however, from this cause of excessive drinking, some men drink too much and thus render themselves liable to heat-cramps. It is within the experience of all that a long cycle-ride or a hard set of tennis induces thirst on a hot day. This is because the body plasma contains about 0·6 per cent. of chlorides, whereas the sweat exuded

from the glands contains from 0·2 to 0·4 per cent. Thus, if a man loses weight by sweating, the salt concentration of his blood will become abnormal and nature gives him a thirst to warn him of the fact; he then drinks and in a short time the salt concentration returns to normal. If, however, a man drinks much more water than he needs, he will experience symptoms due to a subnormal salt content of his blood, or, in other words, he will suffer the effects of water-poisoning.

When the salt concentration of the blood is sub-normal, fatigue and possibly muscular cramps are experienced. It was found that cramp affected those muscles which were under severe strain at the time. The truth of this reasoning was proved by the fact that the urine of a miner who was liable to attacks of cramp showed no trace of sodium chloride after working for a shift. It was evident that his blood was seriously depleted of salt for such a physiological abnormality to occur, and the obvious thing to do was to make him drink salt water. He, and others who were similarly affected, did this, with the result that not only were they cured of cramp, but their lives at home were changed from a state of acute fatigue and inertia to one of brightness and activity. There are some men who, owing to physical disability, cannot conserve their salt supply and for whom the drinking of salt water would be beneficial. The amount of salt to be added to the drinking-water depends upon the severity of the work to be done, but from 5 to 10 grams per gallon of water will generally be found to be sufficient.

Thus it is clear that a simple everyday commodity, in the form of common salt, can be the means of maintaining an increased rate of work-output under trying conditions of climate.

It has been found quite a common practice for men working in hot places to consume more salted food than is otherwise usual. This need for salt is one of the causes for the higher food consumption of miners working in hot and deep collieries. This partly answers the question raised earlier in this Paper as to the need for more food when working in hot places.

The Paper is accompanied by one photograph, from which the half-tone page-plate in the text has been prepared.

Discussion.

The Author.

The AUTHOR amplified his Paper by showing several lantern-slides. The following was a typical analysis of the inspiratory and expiratory air during work:—

	Normal inspired air.	Expired air during work.
O_2	20·93	16·6
N_2	79·04	79·17
CO_2	0·03	4·23

Table VI gave the results of tests on the oxygen-consumption and work-output for various occupations at the coal-face. The Author pointed out that the oxygen-consumption during rest periods was higher than for normal prolonged resting, because the periods of rest were too short to allow the oxygen-consumption to settle down to a constant value and for the respiratory quotient to become steady. In effect, when a man ceased work, an oxygen-debt remained, the elimination of which necessitated the breathing of additional oxygen during rest for a short period of time.

The rest-periods taken by the miners experimented upon varied from 9 to 43 per cent. of the working shift, the average being 27 per cent. It might be considered that that excessive resting-time might be due to the fact that the men were breathing air through tubes and a meter. Recently, however, with the assistance of one of his students, he conducted a time-study upon a hundred miners working normally and not knowing that they were under observation. He found that for them the rest-periods varied from 4·6 to 47·4 per cent. of the working shift, with an average of 25·2 per cent. Those frequent but short rest-periods taken by miners indicated the severity of their work. It made a big demand on oxygen-consumption, and tended to strain the breathing mechanism to a point which necessitated a momentary stoppage of work in order to supply the oxygen-need.

With regard to food, he wished to make a few general observations. If the wages of a manual worker fell too low one of two things was bound to happen; either the man would have to do with less food, and in consequence his work-output would be reduced, or he would maintain his dietary standard and work-output at the expense of his family. Further, a low dietary standard would cause absenteeism on account of illness due to malnutrition and would increase the liability to fatigue during work, thereby making the man more liable to fall a victim to accident.

The Author.

TABLE VI.

Occupation.	Averages for each occupation.									
	Air breathed.			Oxygen-consumption.				Work-output.		
	Average volume of air breathed: litres per minute.	Time over which average was taken: minutes.	Number of men included.	Average: cubic centimetres per minute.	Time over which average was taken: minutes.	Total time: minutes.	Number of men included.	Average: foot-pounds per minute (taken as 12½ per cent. of energy-output).	Average: foot-pounds per minute (from ergometer graph).	Time over which average was taken: minutes.
Resting	14·43	1,180·0	12	542·5	189·0	1,026·0	10	—	—	—
Coal-getting	29·76	1,145·5	10	1,551	389·0	1,145·5	10	2,432	3,943	389·0
Loading	30·45	830·8	12	1,596	226·3	830·8	12	2,624	4,177	226·3
Timbering	27·29	200·3	7	1,348	74·8	200·3	7	2,152	3,394	74·8
Packing	26·54	373·0	3	1,327	73·5	373·0	3	2,115	3,567	73·5
Drilling	26·85	53·5	3	1,416	38·0	50·5	2	2,249	3,423	38·0
Ripping	28·09	101·0	1	1,521	22·0	101·0	1	2,500	4,350	22·0
Miscellaneous	29·98	46·5	4	1,295	5·5	5·5	1	2,052	3,490	5·5

The Author.

He wished to make it quite clear that the energy-output for the same work done was greater in proportion to the degree of stooping during work. The thermal efficiency of work might fall to about 3 per cent. if a man loaded a wagon or tub in a tunnel 3 feet high. He had previously had no idea how low the thermal efficiency of work became under such conditions. It had been stated that a miner ought not to require more than about 3,100 calories of food per day, but he disagreed entirely with that figure, which had been adopted by a research committee of the Medical Research Council dealing with the nutrition of miners and their families. They had based their calculation upon data obtained in South Africa by Drs. Orenstein and Ireland from tests carried out upon a native hammer-boy, who sat down with a hammer-dynamometer between his legs and hammered at the top of a drill. They had assumed that the energy-output thus measured was equal to that of a Rand miner, and therefore also to that of a coal-miner in Great Britain. He felt sure that those present who had first-hand knowledge of mining in Britain and on the Rand would agree with him that Rand miners did not work as hard as British coal-miners.

Dr. Orenstein himself, despite his determination of energy output, had been partly responsible for the Government of South Africa adopting a ration of 4,385 calories for native workers, which was not only adhered to but in some instances exceeded. That in itself proved the absurdity of the recommendation of the Medical Research Council.

Mr. Whitehouse.

Mr. James Whitehouse remarked that he would like to congratulate the Author on the way in which he had dealt with his subject. It was one to which no engineer could be indifferent, because all engineers depended upon labour for their results, and the well-being of that labour must be their first consideration.

The Author had shown the scale of diet laid down for the natives on the Rand, where more than 200,000 natives were fed on a controlled diet laid down by the Government; that diet had quite a high calorie-value, and was well balanced. He himself had no doubt that, as the Author had said, the miner did require more food than the ordinary worker, because of the variety of effort which he had to make; he had to work under very fatiguing conditions which were bound to lead to considerable exhaustion. In such cases as that of the Rand gold-mining industry, it was easy to provide the diet laid down; in fact, it could be shown that a surplus was provided on the Rand, because the farmers in the district prospered by buying the excess food from the compounds, so that there was no doubt that the natives actually received more calories than were required for their work. In Great Britain, however, the problem

seemed to be very different. The miner's input of energy depended on many things, such as the efficiency of his housewife, the number of children in his family, and the number of drinks which he had on his way home, so that it was difficult for the employer to play any great part in determining that input. It could be measured only, he thought, by the wages, which compared very favourably with those of other workers; the difficulty seemed to lie principally in the irregularity of employment. It was not very much use paying a man a good wage for three days a week if for the other three days he was unemployed. It was in that direction, perhaps as a result of amalgamations which were taking place, that some improvement could be looked for. Mr. Whitehouse.

With regard to heat-stroke, of which he had come across a number of cases, it was most important that newcomers should not be put to work in a hot place, as every death from heat-stroke that he had known of happened to a native who was working his first shift, and it was therefore essential to acclimatize them. They were drafted firstly into the cool parts of the mine, and were gradually brought down to the deeper and hotter workings. At the depth of over 8,000 feet, to which the Rand mines were now worked, the rock-temperature was well over 100° F., and it was very difficult to maintain a difference of more than about 15 degrees between the rock-temperature and the air-temperature. In the deeper workings, therefore, it was not easy to maintain temperatures below 85° F., which was that given by the Author as the maximum permissible; he himself knew from experience that that was about the critical figure.

Sir HENRY JAPP said that, while the Paper considered the miner more as a machine than as a man, he was sure that the Author had the greatest sympathy for the miners with regard to the conditions under which they had to work. According to Table I, the miner seemed to be of an average height of 5 feet 7 inches and an average weight of only 10 stone, and he received an average pay of something like 7*s*. per shift, but he did not work six shifts a week, unfortunately. The coal-miners' condition, however, was very different from that of the miners who were employed in tunnelling in London, big, strong fellows who received twice the pay of the coal-miner. During the miners' strike in 1921, he had the pleasure of an interview with the miners' leader, Mr. Robert Smillie, who told him that the men were not so much upset about the low pay which they received as about the pit-head conditions which they had to endure. They wished to have at every pit-head what the miners in Germany had had for several years, namely, proper washing facilities and showers, with individual lockers, steam-heated and air-ventilated, Sir Henry Japp.

Sir Henry Japp.

so that they could take off their dirty mining clothes and hang them there to dry ready for the next day, and go home in fairly decent conditions. He believed that the conditions had been greatly improved since 1921, but there was still room for improvement. The reason for the present conditions was said to be that the coal industry as a whole was not prosperous, and that the price obtained at the pit-head was only 13*s*. 2*d*. per ton, while the cost of mining and getting the coal to the surface was 13*s*. 1*d*. per ton. That left, seemingly, only 1*d*. per ton for the coalowners to pay for royalties, office charges and profit. Householders and manufacturers, however, were unable to buy coal at anything like that price, and it would be interesting to know what made up the difference; but that cheap rate per ton determined the miners' wages. It should surely be possible to increase the price sufficiently to allow the miners to be paid a decent wage and at the same time to give the mine-owners a fair profit. The effect on exports could be countered, as was done in America, by giving a "draw-back" or rebate of the extra price on all exports and on any materials into the cost of which coal entered largely. The effect of modern savings in the use of coal for making electricity, gas and steel had been such that to-day those industries consumed 31 million tons of coal less per annum than they did in 1910, though they obtained bigger outputs. That added to the difficulty of keeping the coal-miners fully employed.

It was interesting to read in the Paper that the loss by sweat of a miner during a shift might amount to as much as 18 pounds, and the method of counteracting the reduction of the salt-content of the blood by giving the men as much as 5 to 10 grams of salt per gallon of drinking water would be most valuable. At a meeting of the Institution Committee upon Regulations for Compressed Air Working Professor J. S. Haldane pointed out that if the wet-bulb temperature in a tunnel were allowed to exceed 80° F., then the men would show great loss of energy. A man unaccustomed to working in an air temperature of 100° F. would be likely to get a heat-stroke. As a case in point, he remembered that when his firm were constructing the East River tunnels in New York a coloured gang came out of one of the tunnels one hot day and told him that the conditions were so dreadful that it was impossible to work there any longer. No superintendent was near, so he himself went down alone into the tunnel to investigate the matter. As he walked along the tunnel he noticed that a considerable stream of water was pouring out of the two 8-inch air-inlet pipes; the humidity and temperature were almost unbearable, but he managed to walk to the face and found that the humidity there was practically 100 and the temperature 102° F. He got

back to the top as quickly as possible and made an investigation; he found that the day before the tunnel had had a blow, and some sand and mud had been blown around the suction of the centrifugal pump which supplied the after-coolers, so that the air-supply of nearly 10,000 cubic feet per minute was being pumped into that tunnel without any after-cooling. He gave orders for the after-coolers to be taken out one at a time and the small tubes cleared of mud, so that they would act once more, but he had only just done so when he collapsed and his face and body turned to the colour of a beetroot. After the doctor had worked over him for about $4\frac{1}{2}$ hours with ice-packs on his head, and with an attendant cooling his body, he told him, "You must never again suffer that condition," and he had taken good care not to do so. Sir Henry Japp.

In conclusion, he would like to offer his congratulations and thanks to the Author, whose Paper would be very useful to engineers and contractors who had to carry out tunnel work where the temperatures were sometimes high, and would help all employers to take better care of their workmen, without whom nothing could be done.

Mr. C. T. A. Hanssen remarked that the Paper gave an account of the type of work done by a miner, and it was amazing to find that instead of using the man as an engine-driver to direct mechanical power he was used as a prime mover, with a pickaxe. A miner could exert a manual output of $\frac{1}{8}$ HP., power for which he received, say, 1*s*. 3*d*. per hour, so that 1 HP.-hour cost about 10 shillings, at least. That, however, was not the worst of the matter. The miner had to work in a very constrained and difficult position so that his actual output was very much less than $\frac{1}{8}$ HP. The Author stated that 65 per cent. was generally lost, so that the cost per effective HP.-hour was actually about 28*s*. 9*d*., whereas the same power could be obtained by mechanical means for a penny. He thought that such an inefficient method should not be tolerated, because cheap coal was essential to the whole industrial system of Great Britain, and was a major factor in keeping down the cost of living. Mr. Hanssen.

The efficient application of mechanical power in mining depended upon the tools and equipment employed. With a good and well-organized installation, he thought that pneumatic power could be made to work cheaper and more conveniently than any other, but many of the present pneumatic installations were very wasteful. An installation had recently been described, for example, where only 28 per cent. of the power supplied was actually used in the pneumatic tools, the rest being lost by leakage and friction in the pipes. Such inefficiency, however, was due to carelessness, and pneumatic power could easily be conveyed in such a way that it was really profitable to use it. Large power-driven units would be more economical;

Mr. Hanssen. there was no reason why a miner should not control a fairly large unit of compressed-air drills in such a way that the cost of cutting might be reduced to 1*s*. 6*d*. instead of 5*s*. or 6*s*. per square yard. There were many other labour-saving inventions which could be used in the coal-field and which would be found very much cheaper than the manual power of the miner himself. Their use would be to the advantage of the miners, who would get higher wages and live in greater comfort, and also to the coal-owners, who at present received very small profits or even, in some cases, were working their mines at a loss.

Mr. Cotterell. Mr. A. P. I. COTTERELL said that he would like to stress the Author's statement, which had been emphasized by previous speakers, that sufficient food alone made possible a sustained output of hard manual work. He was greatly impressed by the fact that although from 4,750 to 5,000 calories of food per day were needed by the miner, yet in the instances given in Table I only the miners in the hot mines received a sufficient amount, those in the last four districts receiving less than the minimum figure. Had the Author calculated that figure for a miner working in an upright position, or did it allow for the increase of 72·8 per cent. in the calorie-value that was required to provide for the energy-output of the miner when working in a very stooping position or on all fours?

He noticed that during the observations recorded in Table II the miner had four different operations to perform. Presumably it was necessary that he should ease the hard work of coal-cutting by attending to the timber, or perhaps the coal-face was so limited that there was no room for any other worker to undertake it. In that connection, new methods of working developed by a miner named Stakhanov had recently been reported in Russian publications to have revolutionized the coalmining industry of Russia—though probably those methods had been adopted to a large extent in Great Britain many years ago. Instead of producing the normal quantity of about 7 tons per 6-hour shift, he had increased it by fifteen or sixteen times. Other miners, emulating his example, had gone even further, and had produced in the 6-hour shift no less than 300 tons. That was the output of the miner himself; when apportioned amongst his extra timbermen and himself it amounted to a productivity of about 5 times greater than previously. The Donetz coal-basin, in which the development was made, soon over-fulfilled its programme of production, and the method was being taken up very actively not only in mining but in other industries throughout Russia. One inference could be drawn which agreed with a previous speaker's suggestion, namely that engineers should be able successfully to adopt more

mechanical methods of winning coal. It might be said that if Mr. Hanssen's suggestions were adopted, and power produced for 1*d*. instead of for nearly 30*s*., an enormous number of men would be thrown out of work, but surely that should not be the reason why an old-fashioned method should be maintained. Mr. Cotterell.

Mr. T. H. Bailey said that the Paper yielded information which was of deep interest to him, as he had followed his grandfather and his father, both of whom were mining engineers, and had been personally acquainted with the industry for seventy years. In his early days he learned by observation to discriminate between workmen as to their capability or otherwise for the work in which they were engaged. There were then no statistics, such as those that the Medical Research Council had published, nor was there any such valuable information as that resulting from the personal investigations of the Author. While there was a wide discrepancy between the findings of the Medical Research Committee and those of the Author, Mr. Bailey agreed with Professor J. S. Haldane in concluding that the Committee were misled as to the average energy-output and the corresponding food-requirements; Professor Haldane had stated that their results were not for colliers only but included their families. Mr. Bailey.

Mechanical or muscular energy and heat-energy represented nearly the whole energy-output of the human body. The energy metabolism was the chemical or physical change in living matter, and that of the resting man was much less than that of the active man. For example, that of a particular man had been found to be 2,397 Calories a day when at rest, but 4,574 Calories a day when working. The increase was 2,177 Calories, of which work amounted only to 546 and heat to 1,631 Calories. Those figures showed the great importance of an adequate food-supply for the manual worker, and the Author was right in his deduction that an inadequate supply would cause a fall in the output of work, an increase in accident rate, due to fatigue, and an increase in absenteeism, due to illness caused by malnutrition. The energy-intake depended on the amount of food consumed, its calorific value, and its quality.

A high moisture-content of the air retarded heat-dissipation, so that the temperature and the moisture in the air-current through the workings were of great importance. In some deep mines the water came through the strata at a high temperature; for example, at the Snowdown Colliery, 3,000 feet below the surface, its temperature was 98° F. It was very important, therefore, to keep the intake-airways free from water. Certain authorities had advised the watering of intake-airways to keep down the temperature of the air in deep mines, but in his opinion that was not advisable. It

Mr. Bailey. was also necessary in deep mines to keep the air from going into the "gobs" or "goafs," which were like ovens, continually giving off heat; the working faces had therefore to be kept in a straight line, with systematic packs which allowed the roofs over the gobs to break down behind them.

Muscular fatigue was considered to be due to the production of lactic acid, carbon dioxide, and nitrogenous compounds, poisoning the nerve-endings; recuperation from fatigue was obtained through sleep, which repaired them. In hot pits night-shifts should be avoided, as sleep in the daytime was always more difficult than at night. Underground officials complained that men tired much earlier on the night-shift than on the day-shift.

Gob fires were often the cause of high temperatures in mines. At Bentley and Brodsworth collieries, near Doncaster, the directors had been perturbed about the great number of gob fires which occurred, and Sir Arthur Markham, Mr. J. W. Fryer, Dr. Haldane, himself and several chemists had been instructed to make inspections and to report upon the best way of dealing with the trouble. They had found that the difficulty was caused by a thin bed of coal lying over and close to the top of the Barnsley bed, which was crushed in the working, the air passing through the breaks.

To sum up the physical needs of the miner, he required good food and water, good housing, and bathing facilities—it was essential to keep the pores of the skin in good condition so that the escape of heat from the body by sweating might not be hindered. For the miner's sake the colliery workings had to be well managed, with good ventilation, cool air, proper supply of materials and machinery, and the workings kept in good order and repair.

The relation of the mind to the energy-output was also an essential one. The medical profession stated that the onset of fatigue was more generally due to the mind than to the muscles. It was the mind which was the source of action. If, therefore, the mind was eager to carry on the work in hand—if, as the saying was, "the man's heart was in his work"—he would work the better. It was therefore advantageous to do all that could be done to interest the miner in his job, in the best methods of coal-cutting, repairs, and the uniform working of the mine, so that he felt himself part of the scheme.

Mr. Hindley. Mr. C. W. G. Hindley remarked that the conditions in the very important coalfields of Bengal and Bihar, where he had been employed for some years, were of interest. The seams in the majority of the collieries there were fortunately very thick, so that the miners were almost always able to adopt the upright position. That advantage was largely offset, however, by the very unpleasant

atmospheric conditions. The temperature underground was Mr. Hindley. generally about 90° F., and it was difficult to get the wet-bulb thermometer below 88° F. A difference of only 2 degrees at that temperature indicated the humidity, which was extremely unpleasant. He knew from personal experience that walking up a grade of 1 in 5 under such conditions could produce headache and lassitude for the rest of the day. The men employed were local tribesmen, mostly less than 5 feet in height and weighing less than 8 stone. Their diet was two meals a day of boiled rice, but very occasionally they had a meat meal. Their shift was 9 hours underground, but in practice they never worked underground for more than 7 to 8 hours. There was difficulty in supplying them with fresh water, but there had been no complaints; none of the men seemed to find the work particularly arduous. At the same time, they worked only for approximately 3 months in the year for short periods, and never more than 4 days in a week, and the only output it was possible to get from them with the greatest encouragement and care and the best welfare work which could be provided in modern conditions was an average of 15 hundredweight in a 9-hour shift.

Professor J. S. HALDANE observed that the Author had given an Professor Haldane. admirably clear summary of the important investigations which he had carried out during the last few years on the physiology of coal-miners and, indirectly, of other men engaged in hard muscular exertion. He would like, as a physiologist, to say that he had no doubt as to the soundness of the Author's results and inferences. Such criticisms as had at one time been directed against some of them were certainly mistaken.

There were two points in the Paper which he wished to discuss. The first concerned the apparently anomalous fact that colliers in hot mines consumed more food. He thought that that might perhaps be due to the extra work which they had to do in producing sweat. Sweat was a specific secretion, produced by internal activity of the sweat-glands, against osmotic and other forms of diffusion-pressure. Its production therefore involved work and corresponding extra oxygen-consumption, but there were as yet no data for deciding whether that was sufficient to account for the extra food-consumption.

The second point concerned the influence of salt in the food or drink. In the course of his other work the Author had observed the existence of occasional attacks of very violent cramp, particularly in the abdominal muscles, among miners working in warm places. That was evidently the same thing as what was well-known as "stokers' cramp"; in view of the constancy of the composition of

Professor Haldane.

sweat, and of the fact that during hard work the secretion of urine was almost entirely suspended, the possibility of acute shortage in the proportion of salt in the body was evident, and its effects would be essentially the same as those of an excessive proportion of water. The function of the kidneys was to maintain constant the proportion of salts and other crystalloid constituents in the blood, but with the kidneys almost out of action an excess of water could not be got rid of, so that what was really poisoning by water might result, although, as indicated by the thirst, there was a deficiency of liquid in the body.

In order to test that theory, his son Professor J. B. S. Haldane had accompanied the Author in a visit to a very hot Lancashire colliery where cases of miners' cramp had occurred, and obtained a sample of the very scanty urine of one of the men. That sample gave, with the very delicate silver-nitrate test, not the slightest indication of chloride. The kidneys were holding back every trace of chloride, while the sweat-glands, which had nothing to do with regulating the blood-composition, were throwing it away recklessly. There was no other known method of producing such a shortage of chloride as was thus found to exist in miners' or stokers' cramp.

His friend and former pupil, Dr. Johanne Christiansen of Copenhagen, had told him that on a lecturing visit to the Faroe Islands she found that a condition characterized by acute abdominal pain had come to be called "Morbus Britannicus," because it affected the British but not the Scandinavian stokers on the trawling vessels. It was commonly diagnosed as appendicitis or impacted gall-stones, and operated for accordingly. The mystery was explained when she discovered that by the rules of the British Seamen's Federation the British crews got no salt meat or fish, while the Scandinavian crews lived largely on salt meat or fish. Shortage of salt, or water-poisoning, seemed always to be associated with sweating, and the more acute cases with sweating during muscular work.

The Author.

The AUTHOR, in reply, remarked that acclimatization played a very important part in efficiency of manual work in high air-temperatures. That had been clearly shown in his work published 12 years ago [1] and in subsequent Papers.

Mr. Whitehouse had pointed out that a coal-miner might have a large family and a wife knowing little or nothing about the purchase or cooking of food, whereas in South Africa the food of the native mine-workers was prepared by an experienced cook. Since the calorie-value of the native's food had been fixed at 4,385 Calories per day, it was further evidence of the need for a higher food-value than that for coal-miners in Britain.

He feared that Sir Henry Japp had misread Table I. It did not

[1] Proceedings Royal Society—B. Vol. 95. (1923.)

state that a miner's pay was 7*s*. a day; in fact, no actual data for wages were shown, though a basis of comparison was given. It was not surprising that Sir Henry had a heat-stroke after being in almost saturated air at 102° F. The importance of the effect of humidity in high air-temperatures upon working capacity was most important, and should be very clearly understood by all engineers responsible for the welfare of their workmen. When the wet-bulb temperature of the air exceeded 85° F., the efficiency of, and capacity for, work was quickly impaired. The Author.

The data given in Table I were obtained in 1922 for miners working under normal conditions involving a good deal of stooping, especially when loading. The estimated calorie-value of a coal-miner's food-requirements (4,750–5,000 Calories per day) was of course based upon normal working conditions, including therefore a good deal of stooping. It was not correct to assume that the crux of the Paper was that a miner could not buy sufficient food to keep up his work-output properly under present-day conditions. The figures in Table I were obtained at a period when the output per man was less than it was to-day. The energy-output figures were determined a year ago. Nowhere did he say that miners as a class were underfed; there was certainly evidence of malnutrition amongst them, but whether that was due to poor wages or to domestic inefficiency of their households was a matter for determination. He had, however, in his introductory remarks (p. 364) pointed out that if the wages of a manual worker were too low he could not purchase an adequate diet.

Mr. Hindley's remarks were most interesting. Some years ago the Author had determined the salt-content of the sweat of several native students from India, and found it to be nearly twice as high as that of an English collier. Those results might not, of course, be normal for natives of India, but, if they were, then it was clear that sweating in mines in India could not produce the same degree of salt-concentration of the blood; hence thirst, and therefore the need for water, was not likely to be so common as amongst coal-miners in England.

An output of only 15 cwt. of coal per shift of 9 hours was not to be wondered at if the air-temperature conditions were so severe, and, more particularly, if the miners' food-input was so very low. He hoped that Mr. Hindley would induce a dozen or more natives gradually to acclimatize themselves to a much higher food-input per day, and at the same time determine their work-output. The result would, he was sure, be interesting and well worth while.

Professor Haldane's contribution was greatly appreciated, for he it was who had inspired most of the practical physiological research in connection with the miner that the Author had done. His advice

The Author.

had always been most readily and kindly given. His contention that the need for more food when working in hot mines might be due to the extra work done by the sweat-glands during the copious secretion of sweat was very interesting, and should be investigated. The Author could hardly believe that that alone could account wholly for the increased food-consumption. It might be that hard manual work, accompanied by profuse sweating, caused a slowing-up of the digestive processes and that, in consequence, an abnormal amount of food passed out undigested.

The cause and cure of "Morbus Britannicus" were both interesting and amusing. Professor Haldane would remember that in the early days at Pendleton colliery the sufferers from cramp were rushed off to hospital and, after an erroneous diagnosis, were operated on for appendicitis.

*** The Correspondence will be published later.—SEC. INST. C.E.

ORDINARY MEETING.

10 December, 1935.

Mr. JOHN DUNCAN WATSON, President, in the Chair.

On the recommendation of the Council, the members present elected by acclamation as an

Honorary Member

THE RIGHT HONOURABLE LORD PLENDER, G.B.E., LL.D.

The PRESIDENT said that at the Ordinary Meeting on the 12th November, at which the first Paper on a subject of current engineering interest was discussed, it had been found that many who had wished to take part in the discussion had been unable to do so, owing to lack of time; it had therefore been decided to accept written communications received within a week after the meeting for publication in the Journal. As the same difficulty might arise again when such Papers were being discussed, written communications would, in the future, be accepted, provided that they were received in time to be published in the Journal with the Paper and oral discussion. The latest date for receipt of such communications would be printed on the advance proofs of the Papers; that for the present Paper was the 16th December.

The following Paper was submitted for discussion, and, on the motion of the President, the thanks of The Institution were accorded to the Author.

"Industrial, Agricultural, and Domestic Heating, with Electricity as a By-Product."

By Sydney Bryan Donkin, M. Inst. C.E.

TABLE OF CONTENTS.

General Considerations and Existing Plants.

Cheap coal and labour, both for industrial and domestic purposes, have probably contributed to the disregard which engineers and the community as a whole have shown in this country towards the question of combining the supply of both heat and electricity from central thermal-electric stations. The prior establishment of one supply or the other has also made such combination difficult of application in present-day cities.

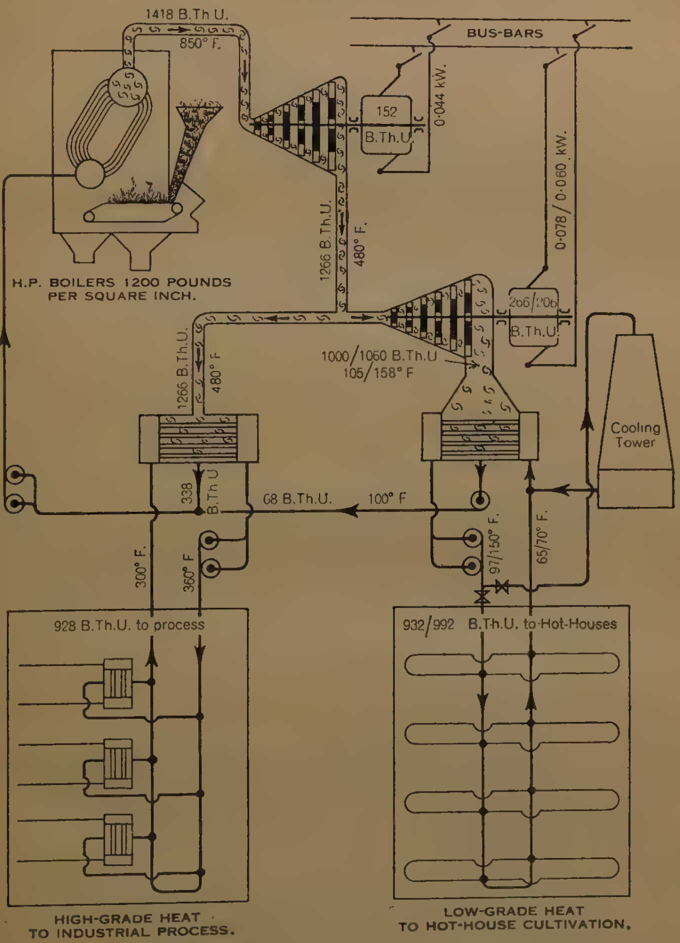
With the highest boiler-pressures and the most efficient plant at present in use the overall thermal efficiency of "straight" electric generation when using coal as a source of energy cannot exceed about 30 per cent. By providing means for using the latent heat in steam for industrial, domestic and horticultural heating, the thermal efficiency of the combined station which generates electricity and utilizes the surplus heat can be raised to 60 or even 70 per cent. where suitable arrangements can be made for the balance between the electricity-demand and the heat-demand.

It is probable that the price of coal will be increased in the near future, and in order to avoid a corresponding increase in the selling price of electricity it is desirable for engineers to examine every possible method of overcoming the difficulty with which the electricity undertakings may be faced. The adoption of the combined electric

generating and thermal-supply station has recently come to the forefront as one of the most economic methods of fuel-utilization.

Fig. 1 illustrates diagrammatically how the latent heat from the steam can be utilized, and shows that it is possible to provide two

Fig. 1.



HEAT-FLOW DIAGRAM PER POUND OF STEAM.

grades of heat when employing a thermal-electric system, one for manufacturing processes, which may be referred to as high-grade heat, and the other for the heating of hothouses, referred to as low-grade heat. Domestic heating lies between these two limits, and is

not shown in the Figure. The cooling-tower on the right-hand side of the Figure would only be in service during the summer months, as the low-grade heat can in most cases be utilized during the winter weather (normally about 6 months). If cooling is available from a river or other source no cooling tower is necessary. On the left-hand side of the Figure it will be noticed that the provision of high-grade heat robs the steam of heat, a small percentage of which could have been used for additional electric generation. This loss in electric power is very much less than the corresponding gain achieved by enabling a large amount of latent heat to be used which would otherwise be lost.

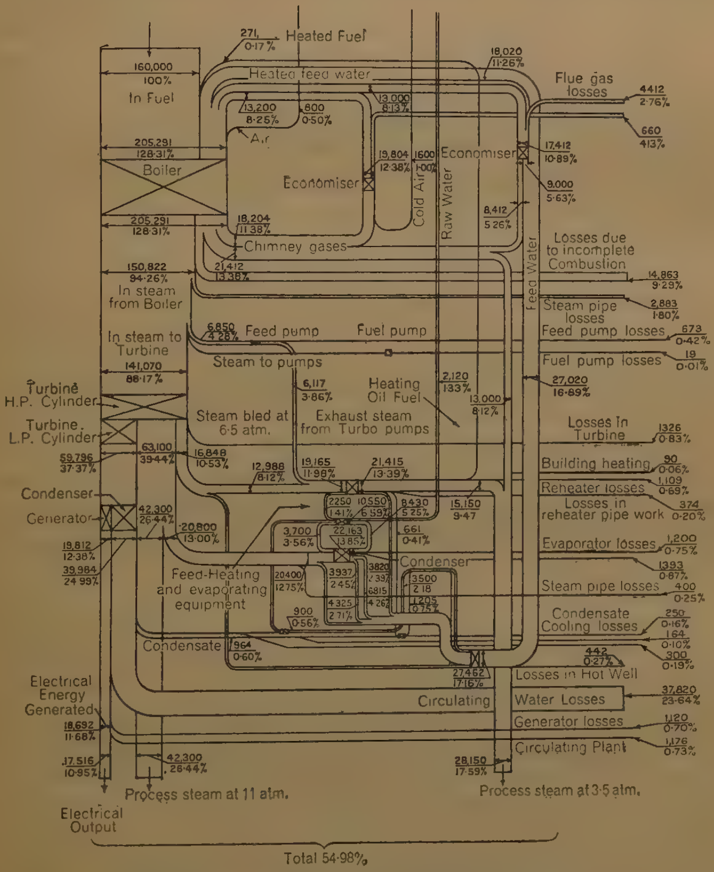
The possibilities of combined thermal-electric stations have long been appreciated, but for a number of reasons developments along these lines have made practically no headway in Great Britain, except in the case of certain large self-contained works. In the United States of America district heating-systems distributing steam and, in some cases, hot water have been extensively developed, but very few of these installations have taken advantage of the fact that with a proportionally small additional expenditure on fuel they could generate steam at considerably higher pressures and temperatures, and, after passing it through back-pressure turbines, feed it to their district heating-networks. There are actually about forty towns where public utility companies are supplying heat and power from combined thermal-electric stations, of which Pittsburg, Rochester, and Peoria may be cited as the leading examples. In Western Europe greater attention has recently been devoted to the problem, and some characteristics of the more important installations of this kind are shown in Appendix I. Descriptions of these stations and operating statistics have appeared from time to time in the technical press, and Appendix II gives a bibliography of the more important articles which have appeared.

By far the largest developments of this kind have taken place in Soviet Russia, where the authorities have been able to make good use of the principle involved in the development of the country's new industrial centres under the first and second Five-Year Plans. In all about sixty-three combined thermal-electric stations have been built. The distribution of heat for domestic purposes has been done with high-pressure hot water. Leningrad has by far the most extensive network in the country, about 20 miles in total length and distributing 416 million B.Th.U.'s per hour. Since 1926, when the development of thermal networks started in the U.S.S.R., some 120 miles of main heat-distribution network has been installed.

The success which has attended the operation of the earlier combined thermal-electric stations (all built after 1926) has led the

authorities in Moscow to embark upon an extensive scheme, under which it is intended that Moscow will ultimately be provided with ten large thermal-electric stations having a total installed generating capacity of 1,426,000 kilowatts and distributing 26,500 million B.Th.U.'s per hour. The first of these—the Stalin thermal-electric station—is already in commission with an installed generating

Fig. 2.



HEAT-FLOW DIAGRAM OF GROSNI INSTALLATION.

capacity of 75,000 kilowatts, but is designed for an ultimate capacity of 250,000 kilowatts.

It is not proposed in this Paper to do more than briefly refer to the theoretical advantages which accrue from the provision of pass-out turbines for supplying heat for various purposes. This subject has been very fully dealt with in various papers which have

been published from time to time dealing with the characteristics of pass-out turbines. An example of the economics of a combined system in a possible new industrial town will, however, be given later.

Although the more usual method of demonstrating the possible theoretical economies is by use of the Mollier diagram, it is probably more convincing to quote examples from actual practice. *Fig. 2* is the heat-flow diagram of the 10,000-kilowatt thermal-electric plant completed in 1928 at the Grosni oil fields in Northern Caucasia. This station is equipped with two 5,000-kilowatt turbines working at 420 lbs. per square inch steam-pressure at 725° F., and passing out 38,600 lbs. of steam per hour at 160 lbs. per square inch pressure, but designed to work as straight condensing sets if required. The diagram presents an indication of the heat-losses, and shows that although the amount of the heat-energy in the fuel leaving the station in the form of electricity alone is in this case only 10·95 per cent., nevertheless the overall thermal efficiency is 54·98 per cent. In other words, electricity is not the major product of the plant.

The overall thermal efficiency quoted is no exception for such stations. Table I shows the figures obtained at four other similar stations which have been built in the U.S.S.R. since 1928. The thermal-electric station at the Beresniki works of the State Chemical Industries ot the U.S.S.R. is a rather special installation of this kind, with an overall thermal efficiency of 58·7 per cent.

A notable British example of a large factory in which the fullest possible use has been made of the advantage gained from combining thermal and electrical supplies is to be found in the Billingham plant of Imperial Chemical Industries.[1] In Great Britain a large number of individual industrial plants have recently been installed, details of which are from time to time published in the technical press. At the carpet-factory of Messrs. J. Crossley and Sons in Halifax a 2,000-kilowatt turbo-generator set has been installed designed to pass out 60,000 lbs. of steam per hour at 30 lbs. per square inch back-pressure. The summer demand for back-pressure steam is 38,000 lbs. per hour, whereas the winter demand reaches 58,000 lbs.

In the majority of cases the heat is taken from pass-out steam from turbines and may be regarded as high-grade heat, but in one or two cases arrangements have been made to utilize the low-grade heat in the circulating water from condensing sets. The thermal-electric plant of the Packard Motor Company's works in the United States may be cited as an example in which the fullest possible use is made of the low-grade heat in this way.[1] The circulating-water pumps are so arranged as to enable the speed of flow of the circulating water to be varied so that the water leaves the condenser

[1] See Appendix II for references.

TABLE I.

Name of thermal-electric station.	Plant installed.	Total generating capacity: kilowatts.	Yearly output of station.		Yearly fuel consumption.		Average thermal efficiency: per cent.
			Millions of kilowatt-hours.	Millions of B.Th.U.	Thousands of tons.	Millions of B.Th.U.	
1st Moscow . . .	1 set; 3,900 kW.	3,900	7·9	309,500	21·0	587,500	57·2
3rd Leningrad . .	2 sets; 4,500 kW. 1 set; 5,000 kW. 1 set; 700 kW.	14,700	26·7	402,000	41·2	1,135,000	43·5
Orechovo-Zuevo .	2 sets; 4,300 kW.	8,600	33·0	309,000	44·3	1,230,000	34·5
Krasnopresnenskia .	1 set; 4,000 kW. 1 set; 3,000 kW. 1 set; 1,000 kW.	8,000	12·9	652,000	35·2	972,500	72·0

NOTE: See also Appendix I.

at any desired temperature between 90° F. and 180° F. The heated water is used for heating the Company's workshops, and the temperature can thus be varied to suit weather-conditions. When the water is allowed to leave the condenser at 180° F. the vacuum is reduced and the steam-consumption per kilowatt increased. This particular installation is of exceptional interest because it indicates the possibility that such low-grade heat may be able to find a considerable outlet in horticultural work, not being confined merely to heating workshops and residences.

Horticultural Heating.

Numerous small-scale attempts have been made to utilize waste heat from industrial plants and power-stations for horticultural purposes, but large-scale development has been slow.

The Klingenberg power-station of the Berliner Stadtische Elektrizitätswerke A.G. may be cited as an example of a station supplying steam to some 57,500 square feet of cucumber-houses, 47,800 square feet of tomato-houses, and 5,160 square feet of houses for cut flowers—in all 110,460 square feet (approximately 2½ acres). These glasshouses are situated at about 250 yards from the power-station and are heated with hot water from heat-exchangers that operate on pass-out steam from the house turbine-sets. The water leaves the heat-exchangers at a temperature of 248° F. and returns at 158° F. The system is designed to maintain a temperature in the cucumber-houses of 84° F. and in the tomato-houses of 66° F. when the outside temperature is 14° F. A small amount of heat is also being used experimentally for soil-heating, but in this connection the Klingenberg authorities have not yet taken the fullest advantage of the benefits that growers are believed to reap from carefully-controlled bottom-heat at the correct periods.

There is without doubt a field for the introduction of horticultural heating as a means of utilizing low-grade heat from combined thermal-electric stations. The one serious argument against placing glass-houses in close proximity to steam-plants is that the growth of the plants is adversely affected by dust, carbon dioxide, and sulphurous fumes. With modern boiler-house equipment, with chimney-heights and chimney-temperatures suitably chosen, and with the scrubbing plants advocated by the Electricity Commission, this difficulty can be surmounted. Such heat in hothouses would allow growers to reduce their "top-heating" charges below those now common with standard heating equipments, thus giving them a margin which would allow them to install hot-water soil- or "bottom-heating" equipment. The heating of soil in tomato-houses by hot water circulated through pipes buried about 18 inches below the surface

has been shown to yield earlier crops and to increase the weight of fruit grown. It is suggested that installations of this kind should, wherever possible, be carefully considered in any comprehensive thermal-electric development scheme.

Equipment of Thermal-Electric Power-Stations.

Boiler-Pressures.

The choice of suitable boiler-pressures for large combined thermal-electric stations has up to the present been chiefly influenced by the limiting maximum pressures for which standard water-tube boilers can be economically built and by the limiting minimum pressure for which it pays to build boilers of the Löffler or other similar types. At the present moment the former maximum limit appears to be about 1,500 lbs. per square inch, and the latter minimum limit about 2,000 lbs. per square inch. The increase in thermal efficiency due to high initial temperatures and pressures in plants of the kind under review is obvious, but, although a few large plants operating at 2,000 lbs. per square inch have been built and put into operation, it would appear that at present a maximum pressure of 1,500 lbs. per square inch using standard water-tube boilers would most satisfactorily meet the case in most instances, particularly when initial capital outlay is taken into consideration.

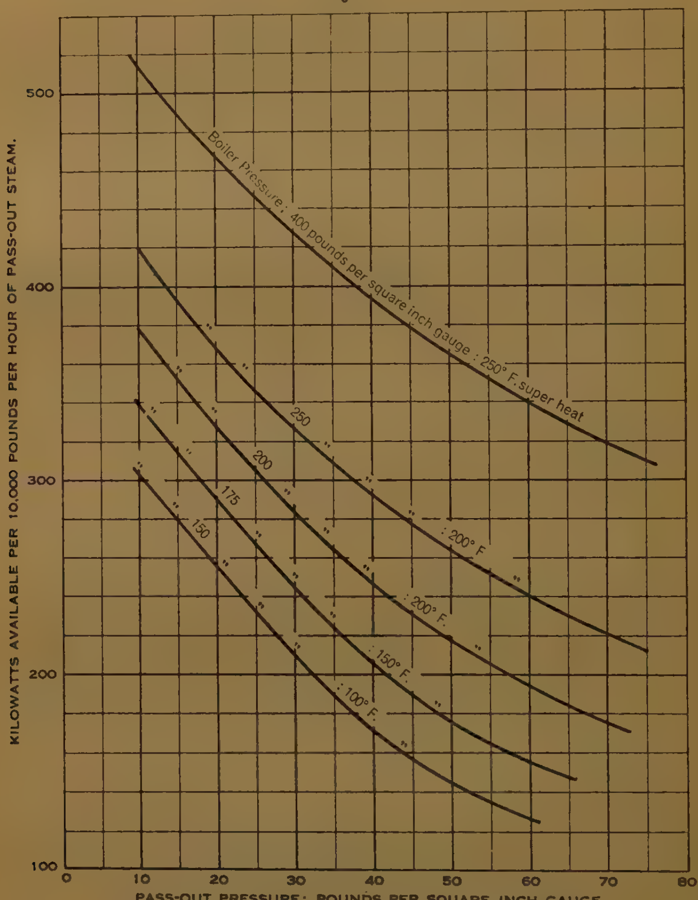
A further limiting feature with regard to boilers is the maximum temperature to which the steam can be superheated. 900° F. is generally considered a safe total temperature, provided that suitable means are adopted to ensure that under no conditions of operation will this temperature be exceeded. Boiler-equipment and steam-distributing and measuring equipment for the pressure and temperature suggested have now passed the experimental stage, and can be installed and handled with confidence. For smaller combined thermal-electric stations supplying individual works such high pressures are seldom justifiable.

Pass-Out Steam Pressures.

The selection of a suitable pass-out pressure for combined thermal-electric stations is dependent on considerations of process temperatures and pressures, and also on the maintenance of proper balance between the thermal and electrical loads on the station. In small industrial installations there is a distinct advantage to be gained by keeping the pass-out pressure as low as possible, as the lower pass-out pressure renders available a proportionally greater amount of electrical energy for the same quantity of steam supplied to the process. *Fig. 3* (p. 386) shows the power available from 10,000 lbs. per hour of pass-out steam at various pass-out pressures and boiler-pressures.

With regard to steam-temperatures in small installations, it is generally desirable to choose an initial steam-temperature which will give about 50° F. superheat in the steam on its leaving the pass-out turbine in order to ensure dryness; *Fig. 4* gives some indication of the superheat necessary at various boiler-pressures and pass-out

Fig. 3.

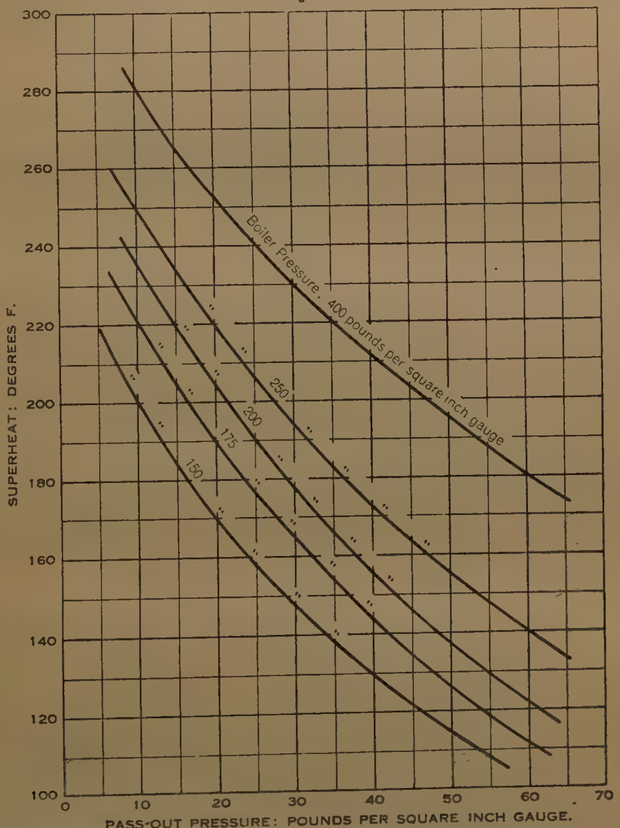


Power Available from Pass-Out Steam.

pressures to fulfil that requirement. In larger thermal-electric plants serving groups of works and supplying heat for districts or for horticulture, and where higher initial boiler-pressures are usually possible, any advantage there may be in having low pass-out pressures with such high initial pressures is more than counteracted by the difficulty of balancing a large electrical load thereby available with

a relatively small amount of available heat for distribution. In such cases, therefore, it is frequently found justifiable to provide higher boiler-pressures and to pass out steam at 150 to 200 lbs. per square inch into a low-pressure system, which supplies steam either to condensing turbine-sets or through heat-exchangers to factory processes as load-conditions demand. This arrangement

Fig. 4.



Initial Superheat Necessary to give 50° F. Superheat in Pass-Out Steam.

permits flexibility in operation, and also renders available process-heat at temperatures of 350° F. to 400° F.

The general trend, during recent years, towards high-pressure hot-water heat-distribution systems has also greatly favoured pass-out pressures and temperatures of this order in large combined thermal-electric plants. Experience has shown that when pipe-diameters and cost of installation are taken into consideration

there is a definite advantage in favour of hot-water distribution at pressures of the order of 150 lbs. per square inch.

Accumulators.

The difficulty of obtaining a perfect balance throughout 24 hours between electrical loads and heat loads in combined thermal-electric stations can be overcome by the installation of heat-accumulators. The cost of such accumulators is generally less than that of additional boiler-plant to serve the same purpose, and in many cases can be justified. If water be used for heat-distribution, this in itself provides heat-storage. At Hamburg a very large accumulator has been installed having a content of 550,000 gallons of water and a storage-capacity of approximately 400 million B.Th.U. The accumulator is of the usual large cylindrical type, of welded contruction throughout. The thermal losses are insignificant.

Turbines.

The turbine does not present any difficulty with regard to the maximum pressures and temperatures at which it can be made to operate, as it can readily deal with the limiting pressures and temperatures determined by the boilers. It is found advantageous in most cases to have two turbines working in series, each with its own alternator, a high-pressure turbine utilizing the steam at its initial pressure and exhausting it at a pressure of about 150 to 200 lbs. per square inch to process work or to a second turbine exhausting to a condenser. This arrangement not only gives greater flexibility but enables appropriate turbine-speeds to be used for the two pressures, resulting in a better thermal efficiency.

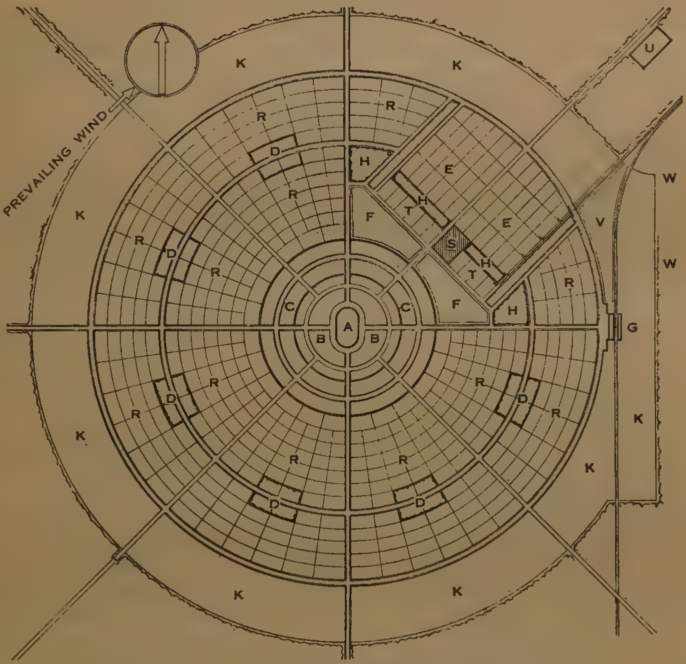
An Example of a Thermal-Electric Plant in Great Britain.

To what extent the combined thermal-electric station is a practical proposition in Great Britain has been the subject of much debate. In our older manufacturing towns the cost of installing the heat-distribution network in their congested streets and the existence of electricity, gas, water, and sewerage services constitute almost insurmountable barriers to its use, but in laying out new industrial areas it presents possibilities which must not be neglected. Such new towns should be planned to provide for a supply of heat and electricity from a combined thermal-electric station and provision should be made where possible for interconnection between the station electrical system and the electrical system of the authorized electricity undertaking in the district.

Various authorities have recently given their support to the idea of creating satellite-towns in certain areas as a means of absorbing

unemployed men into newly-established industries. This affords an opportunity for designing a town with a view to the most efficient use being made of the heat-value in the fuel which is available to industry and other services. An ideal plan of such a town is shown

Fig. 5.



(Scale: 1 inch = 1500 yards approximately.)

DIAGRAMMATIC LAYOUT OF IDEAL INDUSTRIAL TOWN.

A. Civic centre.
B. Commercial zone.
C. Multiple family dwellings.
D. Neighbourhood centres (shops, schools and playgrounds).
E. Industrial.
F. Horticultural.
G. Railway station.
H. Parks.
K. Agricultural belt.
R. Residential.
S. Thermal station; coal-treatment and industrial research.
T. Food factories.
U. Sewage-disposal.
V. Railway sidings.
W. Aerodrome.

Area 2,500 acres. Population 100,000.

in *Fig. 5*; it has been prepared by Messrs. Thomas A. Mawson and Son, architects and town-planning consultants, and the arrangement could be adapted so as to suit local interests and so as not to detract from the amenities of the locality. Particular provision is made for the convenience, economy and safety of traffic circulation; all

main roads are laid out as parkways. Such a town would be planned for a population of about 100,000 inhabitants with a maximum density of 40 people per gross acre and for a thermal-electric station with an installed capacity of 30,000 kilowatts.

The industrial area is specially planned to ensure maximum economy for hot-water and electricity distributing mains.

Inside the industrial zone and close to the power-station are the greenhouses, so that heat may be provided from the condensing water used in the power-station. This enables hothouse cultivation to be undertaken on a commercial scale at a price which should compete most favourably with foreign produce of a similar kind, and at similar seasons. Surrounding the area of land thus to be developed is shown a reserve agricultural belt for farming and market-gardening, and chicken-farms, some of which may require heat.

In order to indicate the economic possibility of such a proposal as that described above in general terms, the following estimates of probable capital expenditure, working costs, and revenue have been drawn up for the scheme shown in *Fig. 6*.

(1) *General Data.*

Output of plant installed	30,000 kilowatts.
High- and low-pressure boiler capacity	600,000 pounds per hour.
Electrical peak load	20,000 kilowatts.
Electrical load-factor	35 per cent.
Electricity sent out	61,000,000 units per annum.
High-grade heat (peak load)	250,000 pounds of steam per hour.
,, ,, ,, load-factor	35 per cent.
,, ,, ,, sent out	6,250,000 therms per annum.
Low- ,, ,, (peak load)	130,000 pounds per hour.
,, ,, ,, load-factor	20 per cent.
,, ,, ,, sent out	1,950,000 therms per annum.

(2) *Capital Costs.*

Generating station, 30,000 kilowatts at £18·3 per kilowatt	£550,000.
Heat-distribution pipework system, meters, etc.	£50,000.

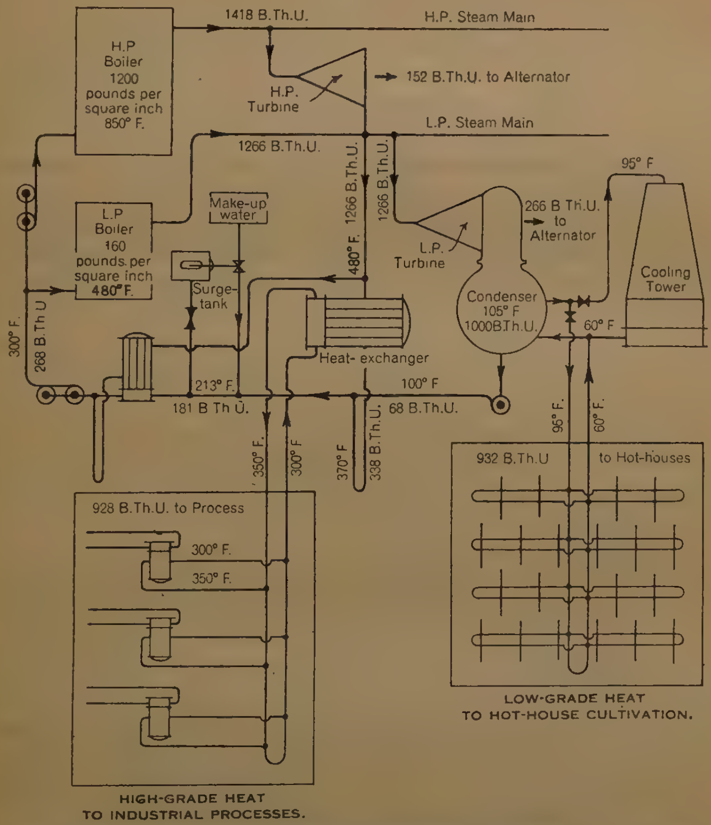
The cost of the combined thermal-electric station includes land, sidings, foundations, buildings, and all plant and auxiliaries, including the pumps and heat-exchangers for the thermal system. No capital cost is included for electricity distribution, as this is common to any scheme, and the revenue from the sale of electricity is calculated from the units sent out at the bus-bars.

(3) *Interest and Sinking Fund.*

Taken as $8\frac{1}{2}$ per cent. on £550,000	£46,700 per annum
Sinking fund at 3·5 per cent. on £50,000	1,750 ,, ,,
Total capital charges	£48,450 ,, ,,

The interest on the capital cost of the pipework, ducts, insulation, etc., for the heat-distribution is not included, but will be added to the cost of the land sold to industries and to prospective residents,

Fig. 6.



Heat-Flow Diagram in B.Th.U. per Pound of Steam for High- and Low-Grade Heat-Utilization.

etc. Sinking fund at 3·5 per cent. is, however, provided from this capital in order to allow for replacement.

(4) *Working Costs.*

Coal at 12*s*. 0*d*. per ton delivered, 12,500 B.Th.U. per pound, including that used for auxiliaries and on works	£35,000 per annum
All other charges	£30,400 ,, ,,
Maintenance, pumping, etc., for heat-distribution	£2,500 ,, ,,
Total . .	£67,900 ,, ,,

(5) *Revenue.*

Electricity, 61 million units at 0·22*d*. per unit	£56,000
High-grade heat, 6·25 million therms at 2*d*. per therm	£52,000
Low-grade heat, 1·95 million therms at 1·75*d*. per therm	£14,200
Total Revenue	£122,200

In a combined thermal-electric station selling heat and electricity, it becomes the duty of the management to allocate suitable charges for both commodities, and commercially it may be expedient to do this without accurate reference to the working and capital charges for each, provided that the total is correct and that a basic minimum is maintained for each. In practice, however, it is obviously necessary to attract custom by fixing a price for each commodity which will show the consumer that it is lower than one at which he could obtain the same results by other means, especially individual generation. In this example the charges for each commodity have been devised on the above lines and so as to bring in a revenue amounting to more than the capital and working costs in order to provide for a reserve of a predetermined amount.

(6) *Balance.*

	£ *per annum.*		
Capital Charges	£48,450	Revenue	£122,200
Working Costs	£67,900		
Balance	£5,850		
	£122,200		£122,200

The effect of selling surplus electricity from the combined thermal-electric station to an outside authority in the winter and buying electricity from their surplus in the summer will probably improve the credit balance shown in the example quoted, especially because with the same plant the electrical load-factor should be improved.

It should also be pointed out that the full working costs of raising steam in the high-pressure and low-pressure boilers are included in the working costs given above, which provides for imperfect proportions in the demand for heat and electricity.

It should be noted that in the above account the prices of the two commodities, heat and electricity, are as low as possible to provide only for an annual reserve fund. If any public utility company developed such a scheme the prices for the two commodities would probably be increased to provide the desirable additional profit.

Mr. H. R. Ayton, in his Presidential Address to the Belfast Association of Engineers, read on 13 November 1935, works out a somewhat similar example;[1] he compares the cost of generating electricity

[1] For reference, see Appendix II.

by a combined thermal-electric station with that of direct generation, and indicates the order of the saving that could be effected.

The greatest practical difficulty in operating a system of this kind is to secure a proper balance between the electrical and the thermal load. Heat-accumulators furnish a physically satisfactory method of accomplishing such a balance, especially in the daily fluctuations, whilst a further desirable improvement can also be obtained seasonally by an interchange of electrical energy with the existing statutory supply-authority. Such statutory authorities would find that small thermal-electric stations could assist them materially with their load-conditions, because in the winter months when large quantities of heat are required the thermal-electric station would have surplus electricity to sell at relatively low rates; on the other hand, during the summer months the demand for heat would be limited to process-work, so that it would probably prove economically sound to shut down much of the plant and purchase the out-of-balance electric power from the area network of the surrounding supply-authority.

The size of central thermal-electric plants is limited by the area over which it is economical to distribute heat, and also, for the application suggested in this Paper, by the generally-accepted principle of modern town-planning authorities that new satellite-towns should be limited in population to a figure of approximately 100,000.

Thermal-electric plants of the type envisaged in this Paper must be regarded primarily as distributors of heat, and the electricity which they generate is one of the saleable by-products which they generate from the fuel with which they are supplied.

The importance of utilizing more than twice as much of the available heat in the coal burnt should prove a conclusive argument in favour of combined thermal-electric stations where these can be installed economically in themselves, and without detriment to existing supply-authorities.

The Author desires to express his thanks to Mr. F. W. Shilstone, Assoc. M. Inst. C.E., for his valuable help in preparing this Paper, to Mr. A. Monkhouse, whose experience in Soviet Russia has made the examples there more easily available, and to Mr. R. W. Mountain, B.Sc., Assoc. M. Inst. C.E., for checking the contents.

The Paper is accompanied by eight sheets of drawings, from some of which the Figures in the text have been prepared, and by the following two Appendixes.

APPEN

CHARACTERISTICS OF SOME EUROPEAN

Plant.	Thermal distribution-system.	Length of lines: metres.	Temperature: °C.	Absolute pressure: atmospheres.
Gare de Lyon, Paris .	Steam	1,000	190–160	11; 7; 4
Copenhagen-Aarhus-Esbjerg.	Hot water	6,300	120° from station; 60° after circulation.	—
Berlin, Steglitz . . .	Steam	4,000	—	—
Breslau	Steam	150 (2 lengths, test).	—	—
Zurich Technical High School.	Hot water	—	—	—
Forst (in operation since 1st January, 1929).	Hot water	1,000 (northern section). 306 (southern section). 879 (branch pipes).	170	6–7 (5·5–6 being sufficient).
Berlin, Charlottenburg .	Waste-steam, hot water.	5,000	—	3
Hamburg	Waste-steam	11,200	—	—

DIX I.

DISTRICT HEATING SYSTEMS.

Number of buildings heated.	Pipe diameter: millimetres.	Type and thickness of insulation.	Capacity: kilogram-calories per hour.	References.
—	250–200	—	13,000,000	*ZVDI.* vol. 75 (1931), No. 38, p. 1206.
—	—	Cellular concrete.	—	*ZVDI.* vol. 73 (1929), No. 28, p. 999.
—	127–363	Cork or cellular concrete wrapped with jute 40 mm. thick.	—	,,
—	—	—	—	,,
—	—	—	11,000,000	*ZVDI.* vol. 73 (1929), No. 6, p. 206.
25 cloth factories (scheduled) at present. Process steam: 6 factories. Heating: 1 factory, 2 schools, 1 concert hall, 1 dwelling-house, 1 office-building, 1 brewery.	600 mm. (main) 7 mm. thick, decreasing to 250 and 156 mm.	"Expansit" insulation of main 5–10 mm. fire-proof coating, 30 mm. layer of *Kieselguhr*, 30 mm. layer of cork, and a coating of gypsum.	—	*Archiv für Wärmewirtschaft*, vol. 11 (1930), No. 6, p. 210.
32	450 (main supply); 350 (ring main).	"Expansit," cork on coating of *Kieselguhr* 50 mm. thick.	—	*ZVDI.* vol. 70 (1926), No. 46, p. 1520.
6 buildings (1921); 40 consumers (1924).	—	—	7,000,000 (1921), 12,000,000 (Feb. 1923).	*ZVDI.* vol. 70 (1926), No. 46, pp. 1511–20.

APPENDIX I—

Plant.	Thermal distribution-system.	Length of lines : metres.	Temperature : °C.	Absolute pressure : atmospheres.
Kiel	,,	8,700	—	—
Berlin, Moabit . . .	—	49 km. (planned).	—	—
Berlin, Neukölln . .	Hot water	2,500 (when complete).	150° out, 70° return.	—
Munich Railway Station	—	2,600	—	—
Dresden (1895, condensate only) extended in 1926–28 to thermal-electric power-station. Hot-water system in 1927–29.	Hot water	—	190	9–12 outgoing, 7 return.
	Low-pressure steam.	—	—	2·5
Dresden (Municipal Hospital and Sanatorium).	—	—	—	4
Dresden	High-pressure steam.	—	200 (max.)	16 (initial) 9 (final).

ontinued.

Number of buildings heated.	Pipe diameter: millimetres.	Type and thickness of insulation.	Capacity: kilogram-calories per hour.	References.
50 consumers (1924).	—	—	10,200,000 (1921), 14,000,000 (Feb. 1923).	Ditto, and *ZVDI.* vol.67, (1923), No. 6, pp. 137–38.
—	—	—	—	*ZVDI.* vol. 70 (1926), No. 46, pp. 1511–20.
14 buildings (Feb. 1921).	228 (max.)	5 cm. *Kieselguhr* and tar board.	—	*ZVDI.* vol. 65 (1921), No. 47, pp. 1219–20.
—	253 ; 216 ; 156	5 mm. coating of *Kieselguhr*, diatomite shell 50 mm. thick.	38,000,000	*ZVDI.* vol. 55 (1911), No. 2, pp. 43–51 ; No. 3, pp. 92–99.
—	Two 250 outgoing, 350 return.	Hot-water and steam mains insulated with spun glass in an asphalt jacket, flue-dust in sheet-iron jacket, or slag-wool in hard jacket separated with magnesium and lambda shells.	Normal load 16,700,000 ; capable of 60,000,000.	*Archiv für Wärmewirtschaft*, vol. 12 (1931), No. 5, pp. 129–39; 233–38.
—	119 (steam pipes). 64 (condensate pipe).		Normal load 1,100,000 ; capable of 2,000,000.	—
—	Two 250 and 180 (steam). Two 180 (condensate).	—	Normal load 4,700,000 ; capable of 7,000,000.	—
—	225 and 175 (steam). 175 (condensate).	—	Normal load 25,000,000 ; capable of development to 35,000,000.	—

APPENDIX II.

BIBLIOGRAPHY OF EUROPEAN LITERATURE ON DISTRICT HEATING SYSTEMS.

Author.	*Title of Article.*	*Reference.*
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—— . . .	Das Fernheizwerk der städtischen Krankenanstalten in Essen.	*ZVDI.* vol. 55 (1911), No. 7, p. 278.
—— . . .	Betriebsergebnisse des Fernheizwerkes für das Rathaus in Charlottenburg.	*ZVDI,* vol. 63 (1919), No. 6, pp. 130–31.
—— . . .	Das neue Fernheizwerk der Stadt Berlin-Neukölln.	*ZVDI.* vol. 63 (1919), No. 30, p. 714.
—— . . .	Städtisches Fernheizwerk Neukölln.	*ZVDI.* vol. 65 (1921), No. 47, pp. 1219–20.
—— . . .	Elektrische Heizung in der Schweiz.	*ZVDI.* vol. 65 (1921), No. 11, pp. 277–78.
Margolis . .	Die Kraftheizwerke in Hamburg und Kiel.	*ZVDI.* vol. 67 (1923), No. 6, pp. 137–38.
Zeulmann . .	Die Anwendung der Elektrizität zu Heizzwecken.	*ZVDI.* vol. 67 (1923), No. 25, pp. 617–22.
Schilling . .	Das städtische Fernheizwerk Barmen.	*Gesundheits-Ingenieur,* vol. 47 (1924), No. 15, pp. 115–19; No. 17, pp. 145–48.
—— . . .	Ein neues Fernheizwerk-Berlin-Zentrum.	*Gesundheits-Ingenieur,* vol. 47 (1924), No. 26, p. 283.
Th. Gaertner .	Errichtung von Fernheizwerken in Berlin.	*Gesundheits-Ingenieur,* vol. 47 (1924), No. 46, pp. 546–47.
—— . . .	Eine zweite Städteheizung in Barmen.	*Gesundheits-Ingenieur,* vol. 48 (1925), No. 6, p. 70.
Ramspeck . .	Das Fernheizwerk der Stadt Schwerin.	*Zentralblatt der Bauverwaltung,* vol. 45 (1925), No. 43, pp. 521–24.
Trautmann . .	Heizkraftwerk Leipzig-Nord.	*Gesundheits-Ingenieur,* vol. 48 (1925), No. 32, pp. 404–06.
H. Schilling .	Die Städteheizung.	*ZVDI.* vol. 69 (1925), No. 27, pp. 889–93.
—— . . .	Die Fernheizanlage des deutschen Museums in München.	*ZVDI.* vol. 69 (1925), No. 29, p. 946.
—— . . .	Wirtschaftlichkeit amerikanischer Fernheizwerke.	*ZVDI.* vol. 70 (1926), No. 31, p. 1050.
E. Schulz . .	Städteheizungen in Amerika.	*ZVDI.* vol. 70 (1926), No. 46, pp. 1511–20.

Author	*Title of Article.*	*Reference.*
E. Schultz . .	Städteheizwerk Charlottenburg.	*ZVDI.* vol. 70 (1926), No. 46, p. 1520.
—— . . .	Fernheizwerk in Forst/Lausitz.	*ZVDI.* vol. 71 (1927), p. 1004.
—— . . .	Berliner Fernheizungen.	*Archiv für Wärmewirtschaft*, vol. 9 (1928), No. 3, p. 74.
A. Margolis .	Grundlagen der Städteheizung.	*XII. Kongressebericht f. Heizung u. Lüftung Munchen u. Berlin*, 1928.
H. Smolinski .	Aussentemperaturverlauf und günstigste Kraftbelastung bei Fernheizwerken.	*Archiv für Wärmewirtschaft*, vol. 10 (1929), No. 4, pp. 153–55.
—— . . .	Fernheizwerk für die Technische Hochschule Zürich.	*ZVDI.* vol. 73 (1929), No. 6, p. 206.
—— . .	Rohrleitungsquerschnitte der Fernheizanlagen Kopenhagen und Aarhus.	*ZVDI.* vol. 73 (1929), No. 28, p. 999.
—— . . .	Fernheizung mit Kühlwasser von Dieselmotoren.	*ZVDI.* vol. 73 (1929), No. 29, p. 1038.
—— . . .	Das Fernheizwerk einer Tuchstadt.	*Archiv für Wärmewirtschaft*, vol. 11 (1930), No. 6, p. 210.
M. Wengner .	Das Hochdruck - Heizkraftwerk Dresden.	*Archiv für Wärmewirtschaft*, vol. 12 (1931), No. 5, pp. 129–39, 233–38.
Jost	Fernheizwerk Halle.	*Gesundheits-Ingenieur*, vol. 54 (1931), No. 3, pp. 33–39.
—— . . .	Fernheizung in Paris.	*ZVDI.* vol. 75 (1931), No. 38, p. 1206.
G. Leunig . .	Betriebserfahrungen in einem russischen Hochdruck-Fernheizwerk.	*ZVDI.* vol. 76 (1932), No. 7, p. 156.
E. Schulz . .	Öffentliche Heizkraftwerke u. Elektrizitätswirtschaft in Städten.	Verlag Julius Springer Berlin W.9, 1933.
R. Ruegg . .	Fernheizkraftwerk der E.T.H. Zürich.	*Archiv für Wärmewirtschaft*, vol. 15 (1934), No. 4, p. 104.
E. Wellmann .	Städteheizung.	*ZVDI*, vol. 79 (1935), No. 25, pp. 763–73.
H. A. Humphrey, D. M. Buist, and J. W. Bonsall	The Steam and Electric Power Plant of Imperial Chemical Industries, Ltd., at Billingham.	Journal of the Institution of Electrical Engineers, vol. 68 (1930), p. 1233.
R. J. Gandy .	Co-ordinating Steam Demands for Heating and Process with Generated and Purchased Power.	*Power*, vol. 68 (1928), p. 864.
—— . . .	Forced Circulation Hot-Water Heating at Packard Plant.	*Ibid.*, p. 882.

H. R. Ayton . Thermal Electric Stations. (Address to Belfast Association of Engineers.) Belfast, 1935.

A. Margolis . Experiences with District Heating in Europe and U.S.A., and its Further Development. Journal of the Institution of Heating and Ventilating Engineers, vol. 3 (1935), p. 361.

Discussion.

The Author. The AUTHOR, in showing a number of lantern-slides illustrating his Paper, remarked that he had prepared it before he knew that its subject would be dealt with by others at about the same time.[1] The subject was evidently, therefore, of current interest, but he hoped that he would be excused if there appeared to be some similarity between his and the other articles.

About 8 years ago his firm had been responsible for installing a thermal-electric station in a large industrial factory in Scotland, and although the owners had not hitherto wished the results of the working of that plant to be published, he was now permitted to give the following results, and to say that the scheme had been found to be most economical in operation. A total of 470 million pounds of steam per year was generated at 300 pounds per square inch and 625° F. (at the turbines), and the pass-out process-steam was delivered at $8\frac{1}{2}$ pounds per square inch and 256° F. The total running cost for 11 million units of electricity sent out was 0·102 penny per unit (including the cost of 21 per cent. of the total quantity of coal used), and the total running cost for process-heat (including the cost of the remaining 79 per cent. of the coal used) was about 0·76 penny per therm. Capital charges and depreciation at a total rate of 13 per cent. on the present depreciated value (adopted by the Company) increased the cost of electricity by 0·14 penny per unit to a total of 0·242 penny per unit, and increased the cost of process-heat by 0·32 penny per therm to a total of 1·08 penny per therm. The overall thermal efficiency was 69·4 per cent.

With regard to the proposed industrial town discussed in the Paper, it was of considerable importance, in planning such a town

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[1] Appendix II.

to ensure as far as possible in its development the right proportion of the demand for high- and low-grade heat and for electricity so as to secure economical operation of the combined thermal-electric undertaking. The thermal-electric station shown in *Fig. 6* would have an overall annual efficiency of 63 per cent. on the basis of the data given. The high-grade and low-grade heat-outputs given in *Fig. 6* were stated in B.Th.U.'s per pound of steam passing through the heat-exchanger and condenser respectively. If heat-accumulators were found desirable, they would probably be connected to the outgoing water-mains, and their cost would not appreciably affect the balance-sheet. In *Fig. 5* a large area was shown for dwelling-houses. It was not proposed to distribute heat to those houses from the hot-water system, as it was considered uneconomical to do so. Multiple family dwellings near the power-station would be supplied. The Author.

Sir Murdoch MacDonald.

Sir MURDOCH MACDONALD remarked that two points in the Paper had greatly impressed him. The importance of the Paper lay primarily in the extraordinary saving of coal which might be effected if the schemes envisaged by the Author were generally adopted. Geologists said that there was coal in Great Britain sufficient for about 700 years at the present rate of consumption. That might sound a long time, but after all, it was only about ten lifetimes; after that time had elapsed, it appeared that the coal on which the power of Britain had been built up would be exhausted. Oil was at present, he understood, used for the production of power only to the extent of about 5 to 10 per cent. of that produced from coal; nevertheless, a vast amount of oil was consumed in Britain, and it was not at all unlikely that a great part of that oil would one day be produced from British coal, which would in consequence be consumed all the faster. From that point of view, therefore, any such suggestion as that which the Author had put forward should be most highly commended. The suggestion itself was not new, but it might be applied in Britain to a very much greater extent than was at present the case. It had been used in Russia, Germany and the United States of America. All those countries had what might be called "Continental" climates—extremely severe in winter and very hot in summer—and therefore such a system would naturally be introduced much sooner than in Britain, but he had been glad to note that a number of small private installations had already been introduced in Great Britain, and it was now possible that private or public companies might attempt to develop the system. If it were adopted the competition between gas and electricity might be somewhat intensified, as it might be possible to produce electricity more cheaply than at present.

Sir Murdoch MacDonald.

The second reason for his welcoming the Paper was that he was glad to think that hot water for domestic heating could be made available. For many years he had asked why that had not been done, and he had always been told that it was not a commercial possibility to pass hot water along the streets and into the houses. There was also a subsidiary advantage, namely, that if hot water from central stations could be introduced into houses on a large scale, the pall of smoke from open fires which hung over cities such as London and Birmingham would be largely obviated, the health of the community would be very greatly benefited, and the deleterious acids resulting from the smoke would be largely eliminated. He understood that it was not yet commercially practicable to run hot-water mains along the streets of existing towns, because the cutting up of the streets was too costly, although it could be done in the case of a new town such as that discussed in the Paper. He felt sure, however, that the day was fast coming when in cities such as London the gas mains, electric cables, telephones and other services would be carried in tunnels under the streets, and when that was done such tunnels could be used for hot-water pipes.

Mr. Donaldson.

Mr. J. M. Donaldson suggested that the real crux of the Paper appeared on p. 393, where the Author stated frankly that the greatest practical difficulty in operating a system of the kind in question was to secure a proper balance between the electrical and the thermal load. He was in entire agreement with that statement. It would be recalled that the working of the system divided itself into two stages. The first was the delivery of relatively high-grade heat obtained from the exhaust steam of a high-pressure turbine. That process was the same in principle as that used in nearly every modern turbine installation, namely, the heating by bled steam of the feed-water; but the system advocated in the Paper was better, in that nearly all the sensible heat obtained from that heat-exchange was made available for useful work, whereas in the ordinary turbine installation it might not be possible to get more than 30 per cent. out. That stage of the system dealt with what might be called process-steam; in certain conditions it was possible to make a reasonable balance between the heat required for process-work and the electrical energy which could be used, but he thought that in the majority of cases the correspondence was by no means good. The second stage of the system, however, was subject to entirely different conditions and the climatic factor became important. In the eastern States of the United States of America, the winter was rigorous, its advent could be predicted to within a week or two, and the probable tempera-ture could be estimated with fair accuracy. In England, on the other hand, winter weather was extremely erratic, which caused very

great difficulty in the practical utilization of the heat available; **Mr. Donaldson.** he did not believe that difficulty could be dealt with by any system of thermal storage tanks, however inexpensive and efficient. He would illustrate the point by reference to the power required to maintain a certain minimum temperature in his own greenhouse, which was not very large, and for the past 5 years had been electrically heated. At first he had kept the minimum temperature to 55° F., but he found that that was rather expensive and produced too quick a growth in certain plants, and he therefore reduced it to 45° F. That was about the temperature used in the Lea Valley nurseries. Meter readings were taken every day throughout the year, with the exception of Sundays and holidays, so that he could tell exactly how many units it took to maintain that minimum temperature of 45° F. over any period. The total consumptions for four successive years were :—

1931	7,500 units.
1932	6,250 ,,
1933	6,500 ,,
1934	5,300 ,,

The difference between the years was not perhaps very notable; the year 1934 was a warm year. The total consumptions for the month of December in each year were :—

1931	1,100 units.
1932	1,147 ,,
1933	1,735 ,,
1934	366 ,,

The variations in that case were more striking, and the figures for individual days showed even greater variations.

The Lea Valley nurseries extended over about 13 miles. It had been the custom, except in a few cases, to design their heating systems on the thermo-siphon principle, with a sunken stokehold. That was no longer the practice, because the underground stokeholds were inconvenient, and pumps driven by electric motors were now used to circulate the water. The pressures in those heating systems, however, were very small, and the pipes were of the drain-pipe type; nor were the joints very tight. If it were possible to connect the heating systems of such a long range of nurseries to a generating station, he thought that the pumping pressure would be such as to make it impossible to keep the pipes tight. They worked at 180° F.; to get that temperature from the condenser it would be necessary to pump fairly fast, and he was afraid that the pumping losses would be very high. It was for those reasons that he thought the proposal was not really practicable for glasshouse heating in England. He

Mr. Donaldson. would also like to mention that he thought the Author proposed too high a price for the steam; he thought the figure for the high-grade steam should be about one-half of that indicated.

Mr. Dolby. Mr. E. R. Dolby remarked that the subject of the Paper had been of the greatest interest to him throughout his career as a consulting engineer. In 1907 he had had the honour of reading a Paper [1] on the heating of some large hospitals, for which he had been responsible. The electric supply was produced by private generating plant, and the exhaust-steam was used for heating water to warm the buildings and to provide hot water for domestic purposes. In 1921 he had read another Paper [2] on the use of exhaust steam.

The Author alluded to satellite towns of 100,000 population, and had shown in *Fig. 5* a scheme embodying circular roads; he did not think that was as good as a rectangular plan. He had recently been responsible for the engineering work in connection with twelve large schools which had been erected on the Becontree Estate of the London County Council. The present population of that Estate was the astounding one of 115,000 people. He did not know whether the authorities had considered any system of district heating but they certainly had not adopted one.

Some twenty years ago he had brought forward a scheme of the character in question in connection with the public baths for the Borough of Wandsworth. At the point where the river Wandle ran into the Thames there was a power-station of the County of London Electric Supply Company, and a few hundred yards up the Wandle there was a large brewery. The public baths were opposite the brewery. He approached the three authorities concerned and suggested to them that low-pressure steam should be conducted to supply the brewery and the public baths. At about the same time he had approached the Westminster Electric Supply Company and asked them whether they could not supply exhaust-steam from their Eccleston Place station for the heating of St. George's Baths in the Buckingham Palace Road. He was sorry to say that neither of his proposals had been accepted.

In conclusion, he would like to point out that the system of district-heating had initially been developed in the United States. In 1893 he had found in Chicago a district-heating scheme at work which was fed from an electric-light station. Since that date a great many towns in the United States had taken up district-heating, and he thought it would be a suitable recognition of the work done

[1] "Methods of Heating Adopted in Hospitals and Asylums Recently Built." Minutes of Proceedings Inst. C.E., vol. clxxiv (1907), p. 91.

[2] "Exhaust Steam; its Employment for Power, Heating, etc." Inst. C.E. Engineering Conference (1921), Proceedings, Section III, p. 17.

by Americans if it received some extra mention in the bibliography given in Appendix II. Mr. Dolby.

Mr. A. H. BARKER remarked that district-heating systems had progressed much more in countries where the temperatures were very much lower than they were in England, for reasons which were evident. In countries such as North America and Russia it would be impossible to live without central heating throughout a large part of the winter, so that the custom which could be obtained by the electricity authorities for their spare heat was necessarily very much greater in those countries than it was in England. Moreover, it was unfortunately true that the average Englishman did not like central heating, and would not have it unless he was forced to do so; district heating was therefore unlikely to make such progress in England as it had made abroad. Mr. Barker.

There could be no doubt that the technical possibilities were great. It was easy to carry out such a scheme wherever conditions were suitable; it might not, however, be possible to make a profit out of it. He had carefully studied a scheme for a new township similar in general outline to that shown in *Fig. 5* of the Paper, examining the question of cost as closely as possible, and he was convinced that such a system as that in question could not be applied to a township of the garden-city type with any hope of profitable operation; if he might criticize some of the figures given in the Paper, he could show how impossible it was. He had found by experiment that about 11 million B.Th.U. per annum was the average amount of heat used by a man of the professional class, who did not restrict the amount of heat he bought because of its cost, whereas a man of the working class restricted his demand to about 3 million B.Th.U. per annum. The Author estimated the cost of distribution of the heat at £50,000. With five persons to a house, the new community discussed would have 20,000 houses. If the whole of the pipe-system cost only £50,000, then only £2 10*s*. per house was allowed for the cost of pipes to distribute the heat, and he did not think anyone who had ever had to get quotations for such work would imagine that a house could be dealt with for £2 10*s*.; his own estimate would be at least twenty times that sum. He did not know how the Author had obtained that figure, but it seemed to him to be very widely astray. The Author had also made an estimate of working costs. The difficulty in that calculation was that the amount of electricity required and the amount of heat required varied quite independently, so that it was necessary to make some provision, such as large and expensive water-containers, in order to balance the difference. When it was considered that the average house could be equipped with its own heating and hot-water supply system for from £80 to

Mr. Barker. £100, and that the whole coal bill of such a house was from £10 t £20 a year, it would be seen that a district-heating scheme involvin the payment of interest on millions of pounds would not pay, as householder would find that he could get his heat from his ow independent system for about a quarter of the amount that h would have to pay if the supply undertaking were to make an profit. A case might be made for the system if working costs wer based on figures such as 12*s*. a ton for coal. He would like to b able to buy coal at that price, and no doubt others would als All the costs in the Paper appeared to be estimated on a ver optimistic scale, but he thought that any system of the kind describe would incur very heavy financial losses indeed if the propose charges of 0·22*d*. per unit and 2*d*. per therm were adopted.

Mr. Fowler. Mr. A. Fowler observed that the Author stressed the applicatio of thermal-electric systems primarily from the point of view o distributing heat, and did not attempt to solve the problem of th large power-station on the bank of a river which was using 25 pe cent. of the calorific value of its coal to generate electricity and 7 per cent. to heat up the river. He would have liked to see in th Paper some figures showing the economics of the stations referre to in the Appendix. The Author, to support his case, cited industria plants which were successfully and economically generating heat with electricity as a by-product. He himself did not think suc stations supported the argument for a central station distributin heat; the carpet manufacturer, for example, could probably sa from hour to hour throughout the year what his heat-demand woul be, and would probably feel that he might just as well use generatin plant to reduce the pressure of his steam as put in a reducing valve and he would probably have a very large demand for heat and small demand for electricity. Would that be the case with a centra thermal-electric plant? It seemed to him that it was not th technician who could answer that question. The technical problem could be solved, as was shown by the Paper. In applying the system to an existing district it would be necessary to forecast exactl what the heat-demand would be. The Author, however, dismisse the possibility of district-heating in existing towns because of th cost of putting the mains in the roads, which was probably the righ view, and suggested that district heating should be inaugurated i new towns. To attract people to a new district, however, it wa necessary to envisage a plant and to be able to state the prices o heat and electricity supplied by that plant. A basis for the necessar calculations had therefore to be found. Should it be assumed tha more heat than electricity would be sold, or *vice versa?* Wa provision to be made for the supply of high-grade heat or of low

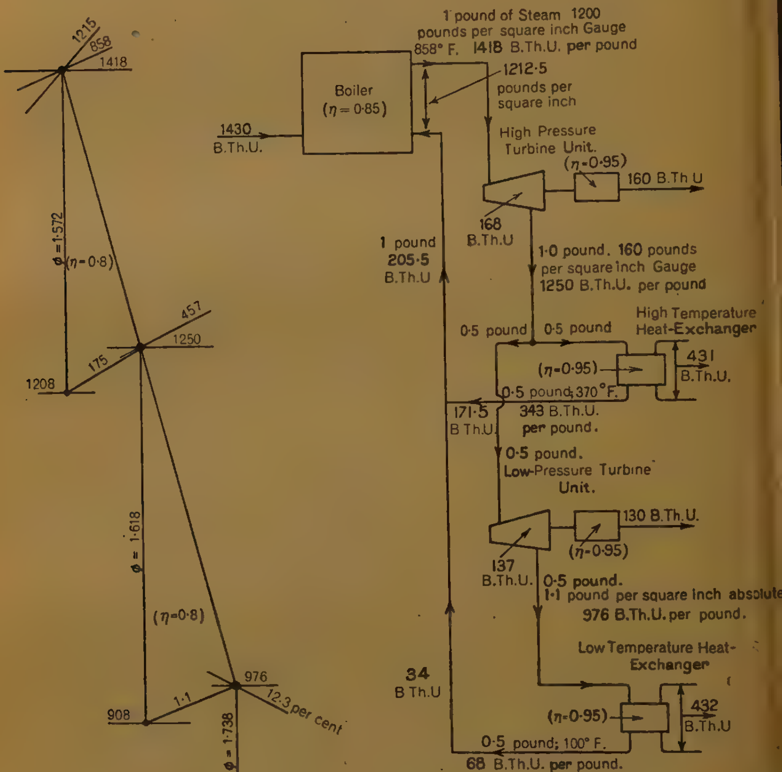
grade heat? To the user of the heat, 1 million B.Th.U. was of equal value whether the distribution-pressure was 200 or 10 pounds per square inch, but to the power-station engineer there was a big difference in the costs of the two. It seemed to him, therefore, that the problem could only be solved by a man of skilled judgment who could look at an area of land and say, "There we will have a rubber factory, here a dye-works, there a man who uses heat all the year round, and here a man who will use it only in the winter." Mr. Fowler.

The New York Steam Company's station, which was primarily a heat-distributing station, had now been established about 53 years, but he believed that it was only during the last 13 years that the company had paid a dividend. The New York Steam Company distributed about 7,250,000 pounds of steam per hour at the peak of their demand, and their boiler-plant raised about 5,250,000 pounds per hour, the balance being taken from the New York Edison Company. Their maximum demand for heat occurred in the early morning, when the buildings were being warmed, but the maximum demand for power occurred in the evening, when the lighting load came on. It was true that the Company was now paying a dividend, but of course in America there was an enormous demand for heat in the winter, because the mean average winter temperature was about 25° F., whereas the mean average temperature in England throughout the seven winter months was 42·3° F. It was interesting to note that the New York Steam Company sold 65 per cent. of their steam for heating purposes only, the balance being used for restaurants, heating washing water, and processing. Such a case was not comparable with that which the Author considered, because in England throughout the year the average proportion of steam sold for heat would not be as much as 65 per cent. Flats provided a fairly good load, but the average occupant of a flat heated only one room during the day. Offices were better, because there nearly every room was heated. However, it seemed that the problems involved in establishing a thermal-electric system could only be solved by a man who could judge just what loads could be obtained.

Mr. C. E. H. Verity, referring to the heat-flow diagrams given in *Figs. 1* and *6*, said that it would be of assistance if the Author would give the weights flowing in the various pipes, in addition to the heat-contents in B.Th.U. *Fig. 1* might appear at first glance to be rather misleading, in that the total heat taken out in the two alternators and the high- and low-grade heat-exchangers was greater than that put in initially from the boiler; that apparent discrepancy arose from the fact that the heat in the whole of the exhaust from the high-pressure turbine was shown as being discharged both to the low-pressure turbine and the high-grade heat plant, whereas in Mr. Verity.

Mr. Verity point of fact half of that heat would be discharged to each. On th basis of the general terminal figures given in *Figs. 1* and *6*, the per formance with high- and low-pressure turbines had been worked ou as shown in *Fig. 7*, the flow being shown on the right-han

Fig. 7.



Heat taken out :—160 + 431 + 130 + 432 = 1,153 B.Th.U.
Heat put in :— = 1,430 B.Th.U.
Overall efficiency :—1,153 × 100/1,430 = 80·7 per cent.
Electrical output as percentage of total output :—
(160 + 130) × 100/1,153 = 25·1 per cent.

side and the steam-conditions on the left. It would be noticed tha on the basis of those figures the overall thermal efficiency worked ou at about 80 per cent., whereas the Author had quoted a figure c 63 per cent., which was probably much more reliable, taking int account, as it no doubt did, the variations in loading of the plant Only 25 per cent. of the total output was represented by electrica energy, so that the plant was largely a heating plant and only to minor extent an electrical generating-plant.

Mr. Verity.

The Author pointed out that with electric generation alone the highest attainable efficiency was 30 per cent., whereas with thermal-electric plants it might be from 60 to 70 per cent. That seemed to be a somewhat misleading statement, because a very large amount of the difference between those two figures was the result of using very low-grade heat at temperatures between 60° F. and 95° F., which was really an attempt to solve the old problem of eliminating the condenser-loss inherent to the steam cycle; most power-station authorities would be quite prepared to provide branches on their condenser circulating-water inlet- and outlet-mains for connection to a low-temperature water-network, and would be prepared to reduce their condenser vacua somewhat in order to raise the temperature of that water, provided that it could be shown that there was a demand for that type of heating which could be catered for at a figure commensurate with the additional capital cost and with the increased cost of electrical generation due to the reduced vacua. The production of a high overall thermal efficiency by such means had very little significance unless it showed improved financial results; it had yet to be shown that a demand existed or could be created for large quantities of low-grade heat for which satisfactory financial return could be obtained by large existing power-stations, though that statement might not necessarily be true in the case of proposed stations to supply new and as yet unbuilt towns.

The essential problem appeared to be that of balancing the thermal and electrical loads, and the thermal efficiency would vary directly with their ratio from, say, 25 or 30 per cent. for an all-electric load, to 70 or 80 per cent. with an all-thermal load. In Table I the Author quoted the results obtained from four Russian thermal-electric plants, and it was significant that in the two plants which showed the highest efficiency (the first and the last in the Table) the electrical loads were only 8·0 and 6·3 per cent. respectively of the total load. It would be of interest if the Author could say whether those figures represented a fair proportion of industrial and domestic heating load to electric load for an average industrial community, whether it was possible that in the areas served by those two stations there was an abnormal amount of industrial plant requiring process-steam, or whether the areas were served by other electrical supplies. In the example worked out on pp. 390–92, the Author considered about 20 per cent. of the total output as electrical energy and 80 per cent. sa heating. Could the Author also give typical summer and winter daily load-curves for any of the various plants to which reference was made in the Paper? Finally, it would be of great interest if the Author could indicate (*a*) the means taken for commercial metering of the high- or low-grade heat, (*b*) the percentage radiation

Mr. Verity. or other losses in a network, and (c) the arrangements of recirculatin pumps required and their power-consumption.

Mr. Beuttell. Mr. A. W. BEUTTELL remarked that he would like to raise a poin which was subsidiary, but might be of interest. He noticed that in the Paper there was no reference to lighting for horticultural work. Extensive experiments had been carried out in the United States of America on the effect of light upon plant growth in heated green houses during the winter.[1] It was initially assumed that the plants would require an intensity of light comparable with daylight, but useful results were found to be obtainable with much smaller illumination; having started with 100 foot-candles, the experimenters found tha certain flowers gave practically as good results with 1½ foot-candles. The Author of the Paper now under discussion had said that a seriou argument against putting greenhouses next to industrial plant was th deleterious effect of the dust, carbon dioxide and sulphurous fumes; if a considerable advantage could be obtained from the scientific application of light, it might offset the adverse effect of those factors. The following figures would serve to show the results that had been obtained. In the case of pansy plants, illuminated with 1½ foot candles for 10 hours nightly for 83 days, the number of blooms was 8·3 times that of the control plants. Asters, with various illumina tions, all flowered a month earlier than the normal time, thus providing blooms out of season. A dahlia plant grew to almost 6 feet in height and bloomed after 4 months, which was a month earlier than the control; the flowers were 7½ inches in diameter, and the tubers had a greater weight than those of the control plant, so that the development was not obtained at their expense. The increase in flowers with a fairly high illumination was 669 per cent., the increase in stem growth 177 per cent., and the decrease in flowering time 28 days. The heat was presumably the same throughout, and the different results were due only to variation in the light. In the case of chrysanthemums the increase in the number of flowers was 226 per cent. and in the stem length 86 per cent., while the decrease in the flowering time was 33 days. The power employed in that case was 19 units per hundred flowers; for the dahlias 272 units per hundred flowers were used.

He put forward that point, not because he suggested that it would add any considerable load to the station, but because it might pro- mote the demand for thermal-electric stations if their application could thus be shown to be more attractive by eliminating the possible

[1] R. B. Withrow, "The Response of Greenhouse Crops to Electric Light Supplementing Daylight." Trans. Illuminating Engineering Society, vol. 29 (1934), p. 65.

disadvantages under which the associated greenhouses might be thought to operate. Mr. Beuttell.

Mr. J. J. S. KENNEDY said that he had had to deal with problems of heat-transmission, and notably that of providing a factory with its requirements of power and of process and building heat. It was not easy to decide between such alternatives as (1) buying electricity for power and using boilers for heat; (2) bleeding turbo-generators; (3) using oil-engine-driven generators for power and their exhaust-gases for heat. The proper decision often depended on the ratio between the units of energy required for heat and for power. He would submit that the problem of supplying power and heat for a town, so ably dealt with in the Paper, was really the same as that for a factory, only on a larger scale. Mr. Kennedy.

In considering the Paper, it should be remembered that coal was the national and natural wealth of Britain. The industrial depression in Britain was coincident in time with lower mine-output, and would end with the return to pre-war output by changed methods of using coal. The nation's coal provided power, heat, and various valuable materials, and the nation should strive to get the most health and happiness from every pound of it. The subject of the present Paper was essentially another method of using coal, so that it had to be judged from the standpoint of national efficiency. The story was that 58 or 60 per cent. of the energy in coal could be utilized for the heat and power requirements of a town, including its homes, gardens and factories. If that scheme was right for one town it was right for all, and he thought that the Paper, carried to it logical conclusion, implied that if it were possible the whole population should be re-housed in towns such as that discussed.

There was, however, another story; in 1926 Britain decided to pool her electric power resources, which was a correct and most fruitful decision. The nation was now learning that it was far better to distribute power and heat by wires instead of in railway trucks. That system, however, entailed using 30 per cent. of the energy of coal for power and heat, and regretfully letting the remaining 70 per cent. be wasted.

From the national standpoint, several questions arose. Were those two conceptions mutually antagonistic, or were they both true? Could they be combined? In other words, ought all the grid super-power stations to be built adjoining model towns of the type which had been referred to, use being made of bled steam for process-work and heating, and all the valuable materials being distilled from the coal before it was burnt?

Mr. ALLAN MONKHOUSE remarked that the Paper foreshadowed important developments which might easily occur in the general Mr. Monkhouse.

Mr. Monkhouse.

attitude of engineers regarding the more economic use of the nation coal reserves. The heat-distribution scheme advocated by th Author provided for industrial heating by means of hot wate at about 150 pounds per square inch pressure, and for the utilizatio of a large amount of the latent heat removed from the steam i large power-stations by the circulating water by pumping that wate through glasshouses erected reasonably near the power-house instead of to the ordinary cooling-tower. The glasshouse heatin would only be a winter load, and would involve running the con densing sets on a low vacuum in extremely cold weather in order t allow the circulating water to attain a sufficiently high temperature Domestic heating was apparently to be confined to heating a few buildings near the power-station. The Author apparently fel that the peculiarities of the somewhat mild British climate made i unprofitable to carry domestic heating mains into the residentia districts far removed from the power-house. If that conception o the Author's intention was correct—as he had reason to believe— he felt that some of the criticism which had been directed at th Paper might have been spared. Widespread domestic heating was not advocated, and it was suggested that hot water unde pressure—not steam—should be employed as a heating medium The use of high-pressure hot water as a heat-distributing medium was not yet common in Great Britain, but the success with which that system had been applied in Soviet Russia, and, to a growing extent, in Germany and Switzerland, led him to think that hot water provided a heat-conveying medium which rendered profitable many heating propositions that might not have been justified if they had utilized the older distributing medium. He felt that the failure of certain steam-distributing systems in the past should not be advanced in criticism of a system utilizing high-pressure hot water, particularly when that hot water was produced at a low cost—thanks to the use of high-pressure turbines, which allowed a considerable amount of energy to be taken from the steam before it entered the heat-exchangers of the heat-distributing system.

With regard to the loads of the Russian power-stations mentioned in Table I, which had been discussed by a previous speaker, the first was a purely domestic heating station with very little process-heat, and the fourth, which had the highest efficiency, 72 per cent., served a chemical and soap works where most of the heat was process-heat. It was strange that those two cases should represent extremes.

One of the most interesting parts of the Paper was that dealing with horticultural heating. He thought that the suggestion of circulating the cooling water through glasshouses presented the most possibilities, but for supplying peak heating in extremely cold

Mr. Monkhouse.

veather he imagined that it might pay better to add heat to the circulating water by steam at 150 pounds per square inch, taken rom the intermediate-pressure line, rather than to reduce the vacuum o low as to have circulating water leaving the condenser at 185° F., s had been done at the Packard motor works installation.

Reference had been made to the effect of light on plants, and some nteresting figures had been quoted by Mr. Beuttell. He himself had een some work on that question when he was visiting the U.S.A. ast year, and the results obtainable with ordinary electric lamps vere as astonishing as they were contradictory. By no means all plants responded to light, and some plants were actually retarded by n excess of light. Perennial chrysanthemums were amongst the atter, and that fact was made use of in the U.S.A. when it was lesired to hold back blooms for the Christmas market. Some very nteresting and complete experiments had been carried out at Purdue University by Messrs. R. B. Withrow and M. W. Richman,[1] vho found that highly beneficial results could be obtained with, in nost cases, remarkably small intensities of illumination. The actual ighting load resulting from the irradiation of plants in glasshouses vould not be large, but without doubt any extensive and up-to-date cheme employing bottom-heat in the way advocated by the Author vould also include facilities for plant-irradiation with light from rdinary incandescent lamps in special reflectors.

Mr. Ayton.

⁂ Mr. Henry R. Ayton observed that Great Britain could not fford to ignore the subject under discussion if she were to maintain ier position as a manufacturing nation. The various branches of ngineering seemed to have become too specialized, and there was ack of co-operation between them, which perhaps accounted for the lowness of adoption of the system discussed. Electric supply was lmost entirely in the hands of specialists, who viewed it primarily rom the standpoint of efficiency, spending thousands of pounds to btain small increases of efficiency, and entirely ignoring the fact hat in an industrial area (particularly one devoted to textiles) a team-supply was as important as a power-supply. Until supply-ompanies offered both services they could not hope to get that large ndustrial load, as private power-plants, properly designed for tilizing the heat in the steam, could produce power at a lower ost than the supply-companies. In America the big utility-

[1] R. B. Withrow, "Plant Forcing with Electric Lights." Circular 206, epartment of Horticulture, Purdue University. (October, 1934.)

⁂ This and the succeeding contributions were submitted in writing.—ec. Inst. C.E.

Mr. Ayton.

companies usually controlled electric, gas and steam services, and therefore, took a broad view and put proper values on each. Whi their initial development had been mainly in connection with heating they now appreciated that the industrial demand for steam ever day in the year was their greatest opportunity, and were now caterin for it. Incidentally, the great development in air-conditioning an refrigeration was producing an ever-increasing demand for stean during the summer, which tended to counteract the lack of heatin demand.

The Author, discussing an ideal industrial town, inferred that th cost of applying the thermal-electric system to existing Englis towns would render it uneconomical. There were, however, man manufacturing districts which were some distance away from th centres of the towns, and were usually surrounded by worker houses. In such cases the system could be applied at a reasonab cost. He had been to America primarily in order to study tha question of the cost of distribution, and had found America authorities to be quite satisfied that it paid them to run steam main in all parts of the cities. They argued that if there were a deman for water or gas in the centre of a city mains would have to b installed to supply it; why should not steam be treated in the sam manner? With regard to the cost of disturbing existing service he thought that if the money spent each year in opening up road and streets to make connections to them, and the loss of busines were capitalized, the cost of a proper tunnel-system would be foun relatively insignificant.

In a modern condensing power-station the steam-consumptio was about 9 pounds per kilowatt generated; while 9 pounds o steam contained about 9,900 B.Th.U., a unit of electricity onl contained 3,412 B.Th.U. It was, therefore, absurd to attempt t supply electric heating in competition with steam-heating, and a engineer had recently stated that electricity used for occasiona heating should be priced at 4 pence per unit (in New York it wa priced at 2½ pence). It was almost a paradox that only whe generated in a thermal-electric station could electricity compet with steam for heating; in such a station about 4,000 B.Th.U would be required to generate a unit, which would contain 3,41 B.Th.U.

He trusted that the Author's Paper would meet with a bett reception from the electric supply authorities than his own [1] had don in Belfast, but he was convinced that sooner or later they would b forced to adopt the system in certain industrial areas.

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[1] See Appendix II.

Mr. T. B. MAXWELL, referring to the statistics given (p. 400) in connection with the thermal-electric station installed 8 years ago in a large industrial factory in Scotland, stated that, as the engineer responsible for its operation, he would like to confirm them. The overall thermal efficiency of 69·4 per cent. might seem to be too high to be attainable, and not likely to be reliable, but the conditions obtaining in the industry which the plant served were very suitable in respect of the ratio of power to heating load. Very great care was exercised to make certain that all records were as accurate as possible, a very full equipment of steam and water meters being installed. Not only were the feed-water to boilers and the steam-flow at important points carefully metered, but, in addition, the condensate from the condensers and the return condensate from the factories were measured, so that a double check was possible on all quantities. It was doubtful whether an ordinary industrial plant could ever attain a much higher thermal efficiency, but it would be interesting to have statistics of other such plants now running. Mr. Maxwell.

When the installation of the above plant was being discussed the question of using part of the heat in the flue-gases (which had an average temperature at the chimney-base of 325° F.) for the heating of air for drying and stoving was seriously considered. Had a site been available for the station nearer to the buildings requiring that supply, very possibly about half of the heat in the chimney-gases could have been used, with a still further increase of the overall efficiency by from 3 to 4 per cent. That would have been particularly advantageous during week-ends when low-pressure pass-out steam was not available. The Author had suggested that the heat in the condensing water could be utilized as a further aid to thermal efficiency, but unfortunately the type of load suggested could not very often be obtained in the neighbourhood of existing factories.

At the thermal-electric station referred to, the process-steam at $8\frac{1}{2}$ pounds per square inch at 256° F. was conveyed to points as far as 2,250 feet from the turbines, and the efficiency of the pipe-lagging was such that there was no appreciable pressure-drop, the amount of condensation being very small indeed.

Colonel R. K. MORCOM observed that it could not be too often emphasized that the thermal efficiency of a well-balanced combined power and heating system could be as high as 70 per cent., because it had been fashionable in some quarters to smother that fact. Under present conditions the tendency to follow the line of least resistance in power-development was dangerous. To centralize generation in ever larger and larger groupings was a simple programme for purposes of propaganda, but it was not essentially right. The provision of exhaust heat or the utilization of surplus Colonel Morcom.

Colonel Moroom.

power seemed to the "simplicity enthusiasts" to be tiresome elaborations. They would raise every possible objection, but none of them was insurmountable. Steam-accumulators could be used to correct irregularities of demand, special switchgear could be devised to prevent any disturbance of phase, and so forth. The problem had been solved by many industrial works with great benefit to themselves. The provision of similar benefits to those less favourably situated was well worth consideration, and in that development new opportunities of stopping the present spendthrift thermal policy would arise. Many years ago he had suggested that a thousand acres of steam-heated glasshouses near each power-house would do much to help the balance of trade by cutting down the import of vegetable produce. All the possibilities could only be determined by practical experiment. The Author's emphasis on the importance of utilizing more than twice as much of the available heat in the coal burned was so well justified that, if the present system of centralization was unable to effect that improvement, it was time to give serious thought to decentralization.

Captain Mullard.

Captain S. R. MULLARD observed that the subject of horticultural heating, to which reference was made on p. 384, was worthy of further investigation; in his opinion any thermal-electric scheme which was started in England should provide for soil-heating. Recent experiments had shown that in districts where the winter daylight was of short duration, namely, the Midlands and the North, the benefit obtained by soil-heating was less than that obtainable in the Southern counties. The daylight, however, could be augmented by the use of low-intensity irradiation, as had been shown by the work of Dr. Withrow in America, to which reference was made by Mr. Beuttell; he was able to confirm that work by his own results of similar experiments on various crops. In any calculation of the financial results it should be remembered that for most crops soil-heating was only required for a period of 10 to 12 weeks in the year, and that the capital and depreciation charges for soil-heating with hot-water pipes were higher than for the usual installation for air-heating in greenhouses. One method of allowing for that increased cost might be to make an annual charge which would represent a portion of the value of the increased crops obtained from the installation of soil-heating and irradiation.

Mr. Partridge.

Mr. H. E. PARTRIDGE thanked the Author for having again drawn attention to the serious limiting features of electrical generation by coal through steam. For some years past there had been a growing regard for coal supplies in Britain, and some had ventured the opinion that the burning of raw coal would soon become a criminal offence. If the burning of raw coal were to be considered a crime

how much more criminal was the burning to waste of 70 per cent. of it! If attention could be riveted to the use of all the intrinsic values of coal, whilst at the same time insisting on its efficient thermal utilization, real progress would be made. Mr. Partridge.

The national grid for electricity supply was no more essential to many industries than a thermal supply, and the development of the small pass-out turbine had enabled economic results to be obtained by industrialists which were the despair or the envy of those responsible for the grid costs. The Author had rightly been conservative in presenting his figures of capital and operating costs, and Mr. Partridge was acquainted with many industrial plants whose results would justify even greater optimism than that expressed in the Paper. He did not overlook the fact that a fuller development of the scheme to embrace domestic requirements would materially affect the load-factor, but, even so, he considered that still further economies could be obtained. Load-factor, having the three variants, electrical energy, process-steam, and hot water, was not a simple problem, and he was of the opinion that the best results would be obtained by the use of accumulators working in combination with varying initial boiler-pressures. The Author in *Fig. 3* showed the work-value of 10,000 pounds of steam under varying conditions; if the turbine-builder would design his machine essentially as a controllable reducing valve capable of operating through a range of inlet-pressure and temperature limits of about 4 to 1, with pass-out steam-conditions variable from say one-half of the inlet steam-condition to full vacuum, then it seemed to become quite a simple matter to meet all load-variations.

He did not expect that the existing electricity-supply authorities would move along the lines indicated by the Author, but, so long as industrialists continued to be willing to incur heavy capital expenditure to obtain results which gave from 25 to 40 per cent. annual return through their power bill, the case could not be ignored, especially as each new installation was the cancellation of a potential grid customer.

Dr. E. G. Ritchie observed that the subject of the Paper represented perhaps the only possibility of making a further substantial reduction in the cost of generating electrical energy in public supply-stations. So far as the supply of low-grade heat for horticultural purposes was concerned, the problem was comparatively straightforward, as the heat-demand for hothouse cultivation was reasonably steady and periods of heavy demand could be anticipated. The supply of high-grade heat to industrial plants was, however, an entirely different matter, as the demand might vary as much as 75 per cent. above and below the average, with peaks whose Dr. Ritchie.

Dr. Ritchie. magnitude varied from hour to hour and from day to day. The Author suggested that the high-grade heat should be distributed as sensible heat in a fluid, for example, water ; in the majority of industrial plants, however, only a certain proportion of the total heat-demand could be met in that manner, the remainder having to be met at a temperature considerably in excess of any that would appear to be practicable by the use of that method. In dyeworks, laundries, and breweries, for example, much of the total heat required could be supplied by means of hot water at about 180° F. without modification to existing plant. That would admirably suit the proposed system. In addition, however, a certain quantity of heat was required at a temperature of about 360° F. It would appear to be difficult to meet that high-temperature heat-demand with the proposed system, without involving the entire re-design of the manufacturing plant. The use of water under pressure and at high temperature for the distribution of heat throughout a works was being developed, but there were many of the more important industries in which conversion to the use of hot water for heat-distribution would be very costly, or altogether impossible. If it were practicable to distribute pass-out steam at a pressure of about 250 pounds per square inch to the various industrial plants in the area of supply, that would provide an acceptable means of linking up the central power-station with the industrial consumers of heat, involving little or no modification to existing plant. There was, however, the difficulty that the steam could not all be recovered as condensate, so that the amount of make-up feed-water required in the power-station might be prohibitive.

Whichever method were adopted for the distribution of high-grade heat, it was obvious that thermal storage equipment would play an important part in the ultimate solution of the problem. All peak-load demands for heat could be entirely suppressed in the majority of industrial plants by the installation of steam accumulators or hot-water storage at each centre of demand, while the distributing system would only need to be designed to suit the average demand. So far as the power-station itself was concerned, there was no doubt that the installation of steam accumulators or feed-water accumulators of conventional type would prove of very great value, as the possibility of supplying both heat and electrical energy to industrial plants at the lowest possible cost depended to a considerable extent upon improving the load-factor in the boiler-house. Such accumulators had been applied with notable success to many power-stations throughout the world.

The Author suggested that, although thermal storage plant represented the correct physical solution of the problem, its cost

was relatively high. The cost of thermal storage plant for power-stations depended to a considerable extent upon the conditions obtaining, but under certain circumstances, and particularly in stations of relatively low load-factor and of the capacity considered in the Paper, the capital cost of thermal storage equipment might be considerably lower than the cost of the boiler-plant it displaced. Actually, in a typical case favourable to the installation of steam accumulators, the storage battery would cost between £4 and £4 10*s*. per kilowatt completely erected. That was less than the cost of equivalent boiler-capacity, apart from which the installation of the accumulator would effect considerable economies in the operation of the station by improvement in the boiler-house load-factor. Feed-water storage also presented important economic advantages where the conditions were suitable for its use. Dr. Ritchie.

The capital cost of installing thermal storage equipment in the individual manufacturing units of a group, such as was contemplated in the Paper, would depend upon the magnitude of the peak loads; in the majority of cases, however, the capital cost would be amply justified as a means of suppressing the peak-load demands for heat and as a means also of obtaining accurate temperature-control. The advantage of thermal storage equipment in that connection had been well established in a wide variety of industrial plants.

In the Paper it was indicated that the charge for high-grade heat would be approximately 2*d*. per therm. That was higher than the total cost of generating steam in a modern industrial boiler-plant, and, if the system proposed were to compete with the privately-owned boiler-plant, it would appear that the cost per therm would have to be considerably reduced. If it were practicable to distribute electrical energy at an average price of 0·22*d*. per unit, as suggested in the Paper, that would permit of the wider use of the off-peak electric boiler, using thermal storage for remote heating and in certain of the lesser industries, so that the load-factor on the generating station would be still further improved.

Mr. GEORGE WATSON observed that there were several instances in which steam was sold for process-work, bringing in a handsome revenue, but that such opportunities were at present very rare. If a good market for surplus heat could be found, it would be of enormous advantage to refuse-disposal undertakings, as well as to electricity-generating stations. The various uses suggested by the Author were perfectly sound in theory, but unfortunately, as he pointed out, heat for horticultural purposes or for domestic and factory heating was required for only about 6 months of the year, and therefore any good scheme to utilize steam for process-work all the year round would be far better. If the heat were sold to horticulturists some Mr. Watson.

Mr. Watson. kind of standby would be necessary, as any possible failure on on frosty night might result in a claim for heavy damages. Bath washhouses, and laundries would appear to afford an all-the-year round market, but unfortunately it was rather a limited one. Th fact that the over-all efficiency of a thermal-electric station might b double that of a plant for electrical generation only showed th immense importance of finding a good outlet for the heat. Th installations referred to in Russia were, of course, working und far more favourable conditions than those prevailing in milde climates.

Mr. White. Mr. BRUCE G. WHITE observed that the Paper emphasized th necessity for proper planning. In Great Britain, with the exceptio of some large undertakings, planning was lamentably deficient, an particularly in regard to engineering. He thought that the absenc of planning in connection with the subject under discussion migh be attributed mainly to the abundance of low-priced coal in Britai and also in some measure to the national characteristic c individualism, which resulted in the power policies of works bein entrusted to the Works Engineers who, excellent though some c them were, might not bring to the subject as broad a mind as wa desirable. He had in mind one or two small examples of lack c planning, such as the Author would hope to overcome. The firs concerned a factory with a heavy demand for processing steam fo agricultural work, the demand arising in a few months of the yea only. It was proposed to establish another agricultural factor within a short distance of the first, and with a steam load in a differen period of the year from that of the factory already establishe The two factories were under separate management, but there wa nevertheless an opportunity for planning the steam load and als the electrical load of the two factories and of any further factorie which might be erected, so that ideal load-conditions could hav been achieved. Another case, of a small nature, concerned a sewage disposal works equipped with steam boilers for operating the pump the engines exhausting to atmosphere. A nursery garden had bee established alongside the sewage-disposal works, some of its glass houses being within 100 feet of the boiler-house of the sewage disposal works, but being heated throughout the winter with wate from coke-fired boilers. Under similar conditions on the Contine the exhaust-steam from the pumping-station would doubtless b utilized in connection with the heating of the glasshouses.

He was greatly interested by the Author's proposal that som system such as that which he described should be utilized in plannin new areas. In his view some of the difficulties experienced b Great Britain were due to the segregation of the agricultural an

industrial areas, leading to undesirable migration of workers from rural to urban districts. He thought that it should be recognized that the facilities for employment in any area should be such as would provide heavy and light manual labour and outdoor and indoor work for both male and female operators, and thus meet the various aspirations of the members of families and communities. Planning such as that proposed by the Author should help to attain that end, as it would enable the various classes of industry, agricultural and manufacturing, to thrive alongside each other. He hoped that the principle would receive serious consideration when steps were taken to populate some of the areas which were now becoming deserted. Mr. White.

Although he realized that the details in the Paper were only put forward by way of illustration of the principle, he felt that he might draw attention to one point with regard to the typical plan shown in *Fig. 5*. In any planning ahead, communication and distribution from railway centres should play an important part, but the railway-station shown on that plan was about 3 miles from some of the residential areas. He felt that, whilst the layout might be satisfactory for illustrating the principle outlined by the Author, it was certainly not so in regard to railway communication; it was vital that planning should be complete in respect of all services.

The Author. The AUTHOR, in reply, observed that three speakers had referred to the fact that the heating of dwelling-houses might be expensive and uneconomical. He agreed, and he had pointed out in describing the layout of the new industrial town, that the dwelling-houses forming a large part of the area were not to be supplied with heat (in the form of hot water) from the power-station, but that only a few large multiple family dwellings would be so supplied, provided that they were near to the power-station. He admitted the possibility of the provision of such heat to dwelling-houses, but in his opinion the practice would not necessarily be found economically possible when considering new schemes. Mr. Barker had criticized the cost of the hot-water distributing system by reducing it to the cost per service for each separate dwelling-house, and the above remarks would show that he was possibly misled in arriving at his conclusions. The Author regretted that he could not at present foresee the ideal conditions referred to by Sir Murdoch MacDonald, and Mr. Monkhouse in his remarks had partly answered those questions. It should be borne in mind that a combined thermal-electric station might be able economically to supply electricity for heating purposes in place of hot water for dwelling-houses, as suggested by Mr. Ayton, especially in the daytime and/or with the application of thermal storage in the individual houses.

The cost, especially of high-grade heat given by the Author in

The Author.

his example and balance-sheet, had been criticized by two speake Mr. Donaldson stating that the figure should be one-half of th given and Dr. Ritchie stating that the cost quoted was higher tha the cost of individual generation. The Author had estimated t figure given of 2*d.* per therm as being a little lower than the avera cost of individual generation, but he pointed out in the Paper th the price of high- and low-grade heat and of electricity could varied to suit the local conditions, provided that the total price the three commodities gave the necessary return on the capital an working costs. In any thermal-electric undertaking it should possible to arrange competitive prices for high- and low-grade hea It would even be possible to halve the cost of high-grade hea provided the cost of electricity and/or low-grade heat could raised in proportion to give the same total revenue. It should borne in mind that the price of electricity quoted was exceeding low, and even so brought in nearly half of the total revenue. Th price was lower than was usual, so that it could be increased necessary and so allow the price of high-grade heat to be reduced proportion. Mr. Barker's pessimistic outlook on the financ possibilities of the example quoted by the Author was not justifie provided that every precaution was taken in the design and arrang ment of the scheme, and in the choice of suitable industries.

Mr. Donaldson referred to the difficulty of supplying low-gra heat to greenhouses on account of the head-losses in the pipes an the cost of pumping. That criticism, however, appeared to app only to existing greenhouses, and the system envisaged by the Auth was one in which a complete new system of greenhouses with pip would be installed, so that the sizes of the pipes in relation to t heat-requirements could be dealt with *de novo*. Mr. Donalds considered that the variation in demand for greenhouse heat England was so great that the use of low-grade heat could n maintain the correct economic ratio of the three commoditi available from a combined thermal-electric station. He though however, that Mr. Donaldson had probably overlooked the fa that all the heat required in the greenhouses, of which Mr. Donalds himself gave an example, would be paid for to the extent (in t balance-sheet) of the heat required for the nights only during abo 4 months in the year, and that at other times when no heat w required the generation of electricity by the low-pressure turbi would be obtained at a low consumption of steam and at a co comparable to that of straight electrical generation.

Many speakers referred to the importance of obtaining the corre ratio of high- and low-grade heat and electricity in order to ma any thermal-electric station and its distribution system a financ

The Author.

uccess. He had discussed that point more than once in his Paper nd indicated methods for dealing with it. Dr. Ritchie had enlarged n the use of thermal storage and on its cost, but the Author vould like to emphasize again the desirability in any scheme of hermal-electric distribution in new industrial centres of entering nto reciprocal agreements with existing electricity-supply authorities n the area, by which the thermal-electric station could supply the uthorities with surplus electricity in the winter and could buy their urplus electricity in the summer. In that way he felt that there vould be no injury to the supply undertakings, but rather that their oad-factors would be improved to their advantage. Referring to Ir. Partridge's remarks, the Author's views on the necessity for the ational grid remained unchanged, as the grid system was required o provide the maximum economy in the generation of electricity hroughout the country.

In regard to some remarks by Mr. Fowler, he wished to state that n developing any new industrial urban centre such as that exemplified n the Paper it would be of the greatest importance to select and ncourage the building of factories and/or horticultural enterprises of uch kind and with such requirements that they would assure a easonably economic ratio of the heat and electricity supplies under verage conditions of operation. Variations in load-factor could hen be dealt with by the methods referred to in the Paper.

Mr. Dolby wanted the ideal industrial town to be rectangular nstead of circular, and Mr. Bruce White criticized the position of and access to and from the railway-station. Those, however, were matters for the town-planning experts.

With regard to the absence of American examples of thermal-electric plants in Appendix II, they had been so fully described in Mr. Ayton's recent address in Belfast that they hardly needed further reference.

Mr. Verity raised a number of detailed questions in regard to *Figs. 1* and *6*. Those diagrams were not intended to show quantities, but to give a simple picture of the systems usually employed.

As an annual thermal efficiency of over 60 per cent. was obtainable in industrial plants, the Author did not agree that the efficiency quoted in the Paper for an ideal industrial town under the conditions stated was misleading. His intentions were to show for such a scheme reasonable financial results. The question raised about the figures in Table I had been answered by Mr. Monkhouse.

The questions of heat-metering, of radiation and other losses, and of all matters dealing with heat-distribution were purposely omitted from the Paper as being outside its scope. Some notes on those points which were the results of practical industrial experience had

The Author.

been given by Mr. Maxwell. Allowances for meters, for heat-loss and for pumping were made in the working costs given in the Pape

He was very much indebted to Mr. Beuttell, to Mr. Monkhouse an to Capt. Mullard for the particulars they gave of horticultur heating and of the application of artificial light. Any lighting f such culture formed an additional advantage to the combin station, and was very welcome.

The interesting remarks by Colonel Morcom were most relevan and the Author wished that the suggestion of placing 1,000 acr of glasshouses alongside a power-station had been tried. The were still possibilities for that proposal in the near future b co-operation between the supply-authorities and the horticulturist

He wished to thank Mr. Ayton and Mr. Maxwell for their remark but thought that Mr. Ayton was a little over-sanguine in suggestin that existing towns could be supplied with heat and electricity fro a combined station. He did not think that it could be do economically at the present time.

He appreciated the understanding of the general problem applying combined thermal-electric stations to new industri centres shown by Mr. Bruce White in his communication, whi pointed out the advantage of combining agriculture with indust in new self-contained areas. He would like to add that such a schem should produce economic results and cheaper living, whilst also should reduce excessive transport.

ORDINARY MEETING.

17 December, 1935.

Mr. JOHN DUNCAN WATSON, President, in the Chair.

The PRESIDENT proposed the following resolution :—

"That the Members of The Institution desire to record the deep regret with which they have learned of the death of Sir Richard Tetley Glazebrook, K.C.B., K.C.V.O., M.A., D.Sc., F.R.S., whom they elected as an Honorary Member in March, 1923, in recognition of the great services rendered by him to the engineering profession and to the nation at large during his Directorship of the National Physical Laboratory.

"They also desire to express their sincere sympathy with the members of his family in their bereavement."

The following Paper was submitted for discussion, and, on the motion of the President, the thanks of The Institution were accorded to the Author.

Paper No. 4977.

"The Treatment of Mud-Runs in Bolivia."

By Stephen William Francis Morum, B.Sc. (Eng.), Assoc. M. Inst. C.E.

TABLE OF CONTENTS.

Introduction.

The object of this Paper is to place on record some notes regarding the treatment of mud-runs, and to outline the methods which have been used in order to overcome interruptions to the service of trains on the Bolivia Railway. The Paper deals mainly with work on the branch line connecting Oruro and Cochabamba, which, owing to its location and to the physical features of the countryside, is the worst line for mud-runs in Bolivia. It was located by engineers who, unfortunately, had had no experience of Bolivian mud-runs, and who thus followed the usual method, and located the line in convenient river-valleys. While they allowed ample outlets for any water which might be brought down by the side valleys, which are really ravines less than 4 kilometres long, they did not allow for much detritus being brought down at the same time. Consequently, when much solid matter was carried down, the mass of detritus and water blocked up the openings and overflowed the track, causing an interruption in the train-services,

Once the line was built, however, it was too late to remedy the defect except in one or two isolated cases, where counter grades were put in or the existing grade was forced in order to allow sufficient head-room under the bridges.

Another reason why a good location was not obtained was the fact that the mud-runs have periods of quiescence when they do not bring down detritus, and the locating engineers, after experiencing a few small runs in the top section of the line, passed through the section from kilometres 115 to 150 at too low a grade level.

In this respect it is interesting to compare this branch with the unfinished Potosi–Sucre line, which was located by the Bolivian Government engineers a few years after the construction of the Cochabamba line by the Antofagasta (Chili) and Bolivia Railway Company. In this case the engineers located the line in hillside cuts in order to avoid the mud-runs, the cuttings being probably some of the heaviest in the world for this class of line. Unfortunately, owing to the loose formation of the countryside, these cuttings have caused exceptionally heavy landslides, and tremendous difficulties have been placed in the way of finishing the line. The idea in locating the line in hillside cuts was to lower the constructional costs of bridges and tunnels, by crossing the mud-run ravines high up on the hillsides where they were small and comparatively harmless; they were then to be deviated from their courses and made to cross the line in open culverts. In this case, too, the engineers, while they had seen the results of the location of the Cochabamba branch, had had no experience in the actual treatment of mud-runs, and they did not give the deviations sufficient grade; the result was that they became choked, the deviating walls were broken down, and the ravines returned to their original courses, causing considerable damage.

While the Author does not claim that the methods used are unique, he thinks that the following description may be of interest to others.

Description of Mud-Runs.

A mud-run, which may occur in any of the mountain ravines, is aptly described in Bolivian Spanish as *Mazamorra* (porridge), as it is composed of a mass of detritus and water, with the consistency of porridge. This mixture varies with the nature of the soil over which the stream has passed, and may, for the purposes of consideration, be broadly divided into three sub-divisions:

(*a*) Shale debris in small particles.

(*b*) Liquid mud (clay) in the form of ooze.

(c) Mud and stones with water. The stones carried may have as large a volume as from 4 to 6 cubic metres in the case of bad runs.

The runs are, however, frequently a combination of one or more of these types, and no sharp definition of a run is possible.

The runs are brought into being by reason of the comparative newness of the geological formation of the country, the severe contortions through which the strata have passed which have broken many of them up, and the torrential rains to which the country is subjected. These factors combine to cause frequent landslides in the ravines, and the torrential streams which occur in these ravines during and after a storm carry the loose material away, both in suspension and by rolling; this mass of detritus and water forms the mud-run.

The causes of these runs may thus be summarized as follows:

(i) The weathering of the shale rock.

(ii) Springs saturating the valley sides and causing the material to lose its angle of repose, and thus to slip down.

(iii) The stream undercutting its banks and thus bringing down slides, which are the foci of the mud-runs.

(iv) A large slide coming into the side of the main valley, blocking the ravine and restraining the stream, which eventually saturates the loose material and bursts through the obstruction, carrying everything before it like an avalanche. This latter is by far the worst kind of run, and when it occurs considerable damage is invariably the result.

The mass of detritus and water formed by the above causes flows down the hillside ravines to the river-valley which, owing to the mountainous nature of the countryside, is often very narrow. When the run reaches the valley, the speed of flow is checked, and the mass begins to deposit the solid matter. The deposit usually occurs near the mouth of the side ravine, but it may, if the rainfall is insufficient, occur higher up the ravine. If a dry season does not occur, during which the deposit will, if not of type "*a*", consolidate into a mass harder than the original soil, the run will then be brought down by the next heavy rain.

If the flow of the main river is insufficient to carry the mass away, the alluvial cone thus formed will be pushed out into the main river, and the bed of the ravine will rise until it bursts its banks in the cone and finds a new course, or until all the loose material in the upper reaches of the ravine has been brought down, in which case it will start to scour.

The first few rains do not usually cause mud-runs, as most of

the water is absorbed by the dry ground, but if, at the commencement of the season, hail and heavy rain-storms occur, large *mazamorras* are generally brought down, as the floods collect all the loose material from the weathering of the surfaces during the dry winter seasons. In some years there are heavy storms all through the season, which keep the mud-runs going the whole time, while in exceptional years, when a steady evenly-distributed rain is experienced, the *mazamorra* valleys are quiescent, as no heavy freshets take place. Usually the year with the least rainfall is the worst for mud-runs, as the ground dries out and cracks, owing to the extreme heat in between the storms, and large slides occur.

The Effect on Location.

The runs naturally have a great effect on the location of railways and roads, as it is necessary to leave the plain of the river and to follow the sides of the main valleys with hillside cuts, in order to cross over the side valleys while they are still small and while they have sufficient grade to keep the mud-runs from depositing. However, this increases the cost of construction considerably, as the line has to be longer and the cuttings heavier, and it is not always economical to carry this out. Owing to the friable nature of the countryside, the danger of large landslides is increased, and, when engaged on the construction of the Potosi—Sucre line, the Author has had to deal with as much as 200,000 cubic metres of slide in a section 10 kilometres long during a rainy season. Thus a mean position has to be determined, and the location should cross the mud-run, with as much head-room as possible, where the run has a good grade.

As well as considering the effect of mud-runs on the same side of the valley as the location of the line, those on the other side must be also taken into account, as a mud-run coming down on that side will divert the main stream against the embankment, and if this bank is at all soft a wash-out will be caused; on the other hand, if the embankment is well defended, or if it is made of rock, flooding, due to the bottling-up of the river, may take place. In addition, mud-runs from the side ravines on either bank may raise the level of the river-bed and cause the river to rise and pass over the tops of the existing defences, or, conversely, the cessation of a mud-run may cause the lowering of the river-bed, in which case the foundations of the defences will be undercut. These features must be considered when a ravine occurs near the location of the line.

The Economics of Treatment.

The usual method of treatment is simply to keep the bridge openings clean by digging a channel for the water and the mud-run; this method, however, is useless in the case of the larger runs, which may leave up to 600 cubic metres of material in the channel three or four times a week and may actually bring down thousands of cubic metres of material which, although it does not remain in the channel, will cause considerable damage. On the Cochabamba line, after a heavy storm, there are often as many as twenty or thirty runs on a section 10 kilometres long. Owing to the track being covered and transport interrupted, the clearing of these and the establishment of a clear line often took a day or even longer.

The first works done were on the lines of some temporary walls built up by the cleaning gangs, and as such good results were obtained, it was decided to treat some of the major runs in the same manner, but as the work to be put in was of an experimental nature, there was some difficulty in obtaining the necessary sanction for capital expenditure. However, a comparison of the figures of the cost of cleaning, repairing damages to the bridges, delays to trains, and transhipment of merchandise and passengers, demonstrated that a considerable saving could be effected. In considering the runs to be treated the fact that some of them are quiescent for a certain period had to be taken into account; this quiescence usually occurs when all the loose material in the upper reaches has been brought down, and whilst there are no further slides.

In practice, before a valley is treated, it has to be carefully surveyed so as to decide which method of treatment will be used or, as is more usually the case, which method is to be used in which part, as the completed work often contains a combination of the various methods. An idea of the grade of the bed that will cause erosion must be obtained, the possible sites for walls or deviations must be investigated and trials must be made to see if any visible rock is in good condition; it must be also ascertained if any building material can be obtained in the vicinity of the projected work. In most of the valleys one or two good sites for walls can be found, and generally speaking there is a fairly good supply of stone which has been left behind after the lighter material has been washed down; but there are some cases, however, where there is no stone, and these need separate treatment. Before treating a run it is necessary to make the survey and take out the comparative costs already mentioned in order to ascertain if the capital expenditure entailed is warranted by the saving in maintenance costs. A budget may then be drawn up on the lines shown in Appendix I.

METHODS OF TREATMENT.

The earliest attempts at treatment were as follows :—

In the case of some of the smaller runs, cross walls made of dry stones or *chipas* [1] were so placed that they retained the loose material in the lower reaches. These proved fairly successful, except for the fact that the specific gravity of the mud-run was nearly equal to that of the cross wall, so that when the run was flowing the top stones were often rolled off the wall, and unless they were carefully supervised, the walls were soon destroyed.

At the same time an attempt was made in one of the larger valleys to drain off the hillside springs and to carry the water thus obtained, together with that due to rainfall, in wooden flumes over the loose material. Owing to the extensive nature of the slides this method was not satisfactory, as the movement of the hillsides disconnected the flumes and allowed the water to escape and do damage; in addition, the flumes often became choked by material falling or being washed into them, and were themselves washed away by big storms.

An attempt was made to pass some of the smaller runs over the railway track by means of wooden shoots. These were not very successful, as not only were they liable to choke up and overflow, but they were speedily destroyed by the abrasive power of the mud-run. To have been of any value the shoots would have had to have been made of concrete or masonry with a facing of hard stone, and to have been of a considerable length to obviate the danger of the overflows; in effect, they would have been a type of artificial tunnel, and they were not practical, in the first instance for economic reasons, and in the second place owing to the difficulty of getting good foundations where the track passes over a run of any magnitude.

In the case of some of the runs, mostly composed of shale debris, cross walls were tried, consisting of a wire mesh supported on posts made of lengths of 60-pound rail. These were not very successful, as they could not be built high enough, nor were they able to withstand any great weight of material. All these walls were very liable to damage.

These attempts led to the methods in use, which are:

(1) Deposit and counter-erosion cross-walls, for runs caused by condition (iii)[2].

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[1] *Chipas* consist of a rough block of small stones built up by hand and encased in a wire mesh, which holds them together in a semi-flexible block.

[2] *Ante*, p. 428.

(2) (*a*) Supporting cross-walls. (*b*) Supporting earth dams. (3) (*a*) Deviations over rock. (*b*) Deviations in paved channels over soft material.	For the other types.

These methods may be considered in turn.

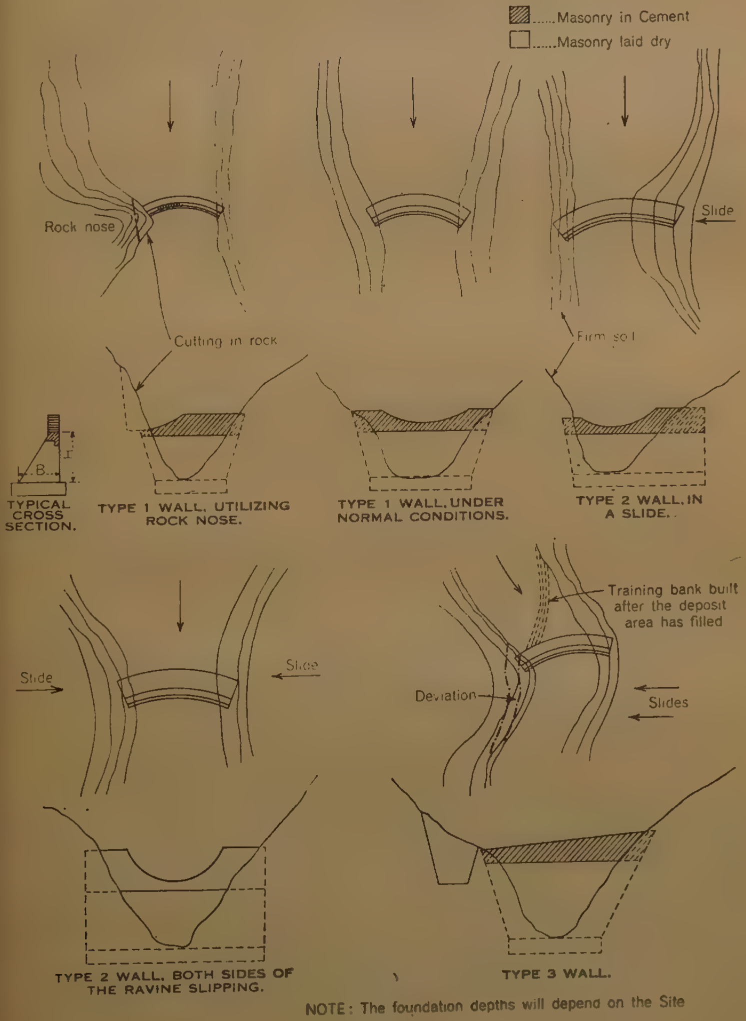
(1) This method is usually employed in the case of small valleys where the sides are not slipping, and the run is caused by erosion and small quantities of material falling from the sides, or where the upper reaches of a larger run are being treated. The object of the walls is to form a deposit for any material held in suspension and, at the same time, to break up the grade and check the speed of flow. To prevent the stream removing any more material, similar walls are used where the bed of the stream is being eroded.

These walls are usually constructed of dry stone masonry arched on to the sides of the valley, and the two upper courses are laid in cement in order to prevent their being washed off and the wall broken down. This type of wall is very suitable, as it readily allows the trapped material to drain and dry quickly. The top of the wall is built in the form of a curve so as to direct the flow into the middle of the valley, as shown in ***Figs. 1*** (p. 433).

The location of these walls plays an important part in the success of the treatment. They are placed in a series in the parts of the valley to be treated and, as far as possible, in any narrows that follow immediately after a wider reach of the valley, with the object of economizing in masonry, making a stronger wall and giving a large deposit area. The bottom wall of any series should have either a stable foundation on rock or else be founded as deeply as possible, and be provided with an apron ; otherwise its foundations are likely to be scoured out, for, when no debris is being brought down from above it, the stream will tend to scour the portion of the valley below it. The height of this wall will depend on the next available site farther up the valley and, if possible, it should be high enough to allow the new bed-level of the valley to coincide with the old wall at that point, as shown in ***Figs. 2*** (Type 1, p. 434). The grade of the new bed will be determined by the local conditions, such as the catchment area, the size of the gorge, and the class of soil, and it ranges from 1 per cent. to 6 per cent. The second wall, placed as already described, does not need a rock or deep foundation as, except for the effect of the water flowing over it and splashing at its toe, it is secured from being washed out by the lower wall. It should be founded in proportion to its height. It is therefore usual, when employing this method, to build walls at strong points, each to act as the lower wall of a series. As these fill, further walls are built

in the portions of the valley between them, until each series is completed. In some cases, where good-sized stone has not been available and where the run does not carry stones of a damaging

Figs. 1.



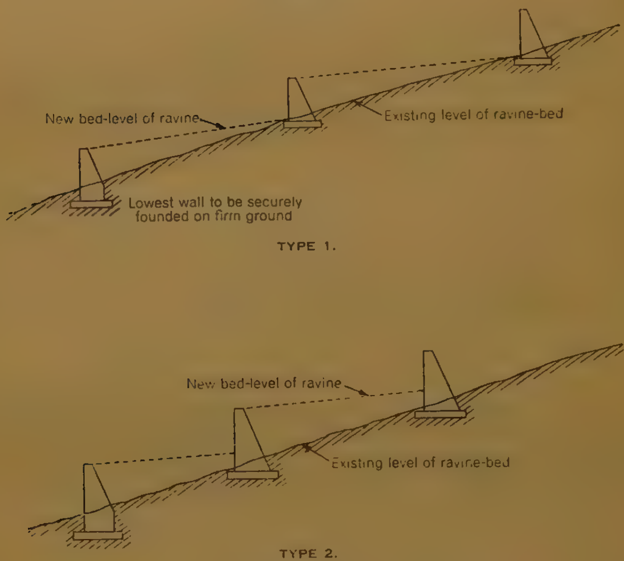
size, the walls have been built of *chipas*, although these do not last as well as cross-walls, and need frequent inspection. Only small valleys, requiring walls up to about 5 metres wide, have been treated

in this way as, in the case of larger ones, a slide in the side of the valley is usually found to be causing the mischief. However, those valleys which have been treated in this manner have given good results.

(2) The object of this method is to arrest the landslides which are causing the formation of the mud-run. This is achieved by means of raising the bed-level of the valley, so that the toe of the slide is supported, and of keeping the flow of water as far away from the slide as may be possible.

(*a*) In valleys where building stone is available, this is done by means of cross walls. The walls, on the whole, are similar to those

Figs. 2.



built for method 1; they are, however, higher and not so definitely arched, except in the case of walls built at the lower end of the slide, as in *Figs. 1.* The reason for this is that the pressure from the slides tends to assist the stability of the arched wall, and any over-arching might lead to the slide destroying the wall.

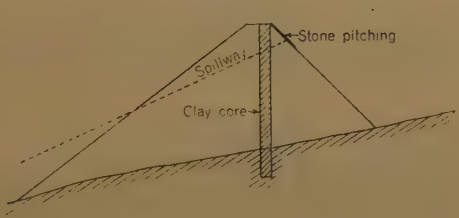
These walls are built in dry stone masonry with the two upper courses of large blocks laid in cement, to prevent their being washed off, and they are curved so as to keep the water from the slide and, if the opposite side is hard enough, to direct the water on to it. The walls are located in a series, as with the first method, with the exception that a cover of from 2 to 3 metres of the bed is obtained

at the toe of each succeeding wall, before that wall is built; thus the second and third walls are almost founded on artificial ground, as shown in *Figs. 2* (Type 2). These walls are only placed in those portions of the valley that are actually sliding.

(*b*) Where no building stone is available, use has been made of earthen dams (*Fig. 3*), the water being taken off by means of a channel, paved if necessary, running from one side of the top of the dam over firm ground. The up-stream faces of the dams are also paved to some distance below the invert level of the overflow channel, to protect them against erosion.

(3) This method is usually only carried out where it is possible to deviate the stream over good rock, as paved deviations, except in special cases, are too expensive. This is due to two facts: firstly, that the sides of the valleys are very steep and, if they consist of soil, much greater excavations are necessary than would have been the case had they been of rock, and that, in the case of

Fig. 3.



deviations made in soil, the channel must be thrown farther into the hillside; and, secondly, that the haulage of the stone to the site, which invariably entails man-handling, makes paving very expensive. On the other hand, in the case of good rock, although the actual excavation is more expensive per unit, the cut can be made nearly vertical and no paving is needed.

The stream is captured above the slide by means of a deviation-wall and, if necessary, its bed-level is raised to allow for a good location of the channel. The channel follows the physical features of the side of the valley as far as possible, in order to avoid big cuttings and to give a grade sufficient to prevent any silting-up. It is extended so as to pass the slide, and the stream is then returned to the valley by allowing it to cascade over either a rock or a paved face.

Design of Cross Walls.

The problem of the efficient design of cross walls to retain mud-runs is a very difficult one to approach, as there are so many factors

concerned. Actually, it is probable that the location selected and the workmanship of the construction play a very considerable part in the success or failure of the structure. Care must be taken to ensure that the toe is safe from erosion by ensuring that it is either founded on good soil, provided with an efficient apron, or has sufficient "cover" from the walls placed lower down the valley. Again, the curvature of the top, the arching, and the amount that the wall is embedded into the sides of the valley must all be carefully considered on the site, so as to ensure that it will be neither washed out at either side nor crumpled up by the slides—which will be the case if it is "over-arched"—and thus placed at the mercy of the next big mud-run.

After settling the location, the characteristics of the valley must be ascertained; that is, the class of material that is brought down, the speed of "flow-off" and the probable quantity that will be brought down by any live flow, in order to get an idea as to how far the wall will fill up during the first mud-run that it has to withstand. Actually, a fair idea of this could be obtained by intelligent use of the data of material cleaned off the track, which is recorded for maintenance and budget purposes. The walls in use have all been designed empirically after taking the following considerations into account.

When liquid and running, the mud-run has an angle of repose of only from 5 to 10 degrees, and has a water-content of 50 per cent. or more, while, when dried out by the sun, it settles and shrinks into a compact mass that is harder than the original soil, with an angle of repose of from 60 to 80 degrees. This is true of all mud-runs except those consisting largely of shale. As the material is deposited behind the wall when it is in a liquid condition, the actual angle of surcharge behind the wall will be equal to the angle of repose whilst it is actually flowing, and this will be the most difficult consideration. Further, the impact of large boulders rolled down the valley by the mud-run, and, in the case of type (iv)[1] runs, the impact of the released water from behind an obstruction in the valley, must be considered. Fortunately, these are not cumulative, as the first rush of water does not carry much material at its head, owing to the fact that the water flows off at a greater velocity than the rolled material, and once sufficient material has been picked up to form a proper mud-run, which flows at a very much slower velocity, the first impact is over.

Against these considerations may be set the fact that, except in exceptional cases and under unforeseen circumstances, it may be

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[1] *Ante*, p. 428.

assumed that the wall will not fill up in any one run and that, as it is of dry stone, the material behind it will drain rapidly and soon assume a larger angle of repose, which will assist the stability of the wall.

These factors are considered, and after allowing a factor of safety for cloudbursts, which is balanced out against any additional strength from arching, the empirical design used is :

> Top width not less than 1 metre, and base width equal to from two-thirds to three-quarters of the height of the wall.

In some of the older designs, which were not sufficiently arched, the base was even made equal to the height. These dimensions are, of course, altered in order to suit the needs of the valley under consideration.

There have been so many difficulties in the way of obtaining a good theoretical design, both from the lack of experimental data and also from the difficulty of obtaining it, that none has yet been put into use. The Author has, however, made some experiments, and he advances these, together with the necessary calculations, in support of the empirical design in use ; the calculations are printed in Appendix II.

Design of Earthen Dams.

These are constructed with a 1-metre thick *tapial* [1] core founded some 2 metres below the base of the dam to prevent seepage. The foundation for the dam is made by clearing the ground, stepping it if it is sloping to any degree, and then tamping the whole site. The dams are end-tipped in order to form a width of 2 metres at the top, the material being allowed to assume a slope of between 3 to 1 and 2 to 1. They are designed to fill to a level of about 2½ metres, or more if necessary, below their tops, from which level any excess of water is led off by means of a rock deviation or paved ditch made on firm ground, and then cascaded down into the original valley clear of the toe of the dam. The up-stream face of the dam is pitched with stone from the top down to about 1 metre below the invert of the deviation ditch.

These dams are constructed on a large scale, and therefore for any given slide there would be fewer dams than cross walls, if the latter had been constructed as an alternative. As a result of their being larger the dams only fill slowly, and each layer of deposit has

[1] Clay and chopped fibrous grass mixed, damped and tamped down in moulds.

a chance of drying slightly and of assuming some angle of repose before more material is brought down, so that the resultant weight on the dam is not as large as would be the case if it were completely filled by one run. The filling of the dams is safeguarded by the fact that the first rains are practically absorbed by the dry ground, so that the first few *mazamorras* do not usually bring a great quantity of material; thus, while it may take three or four storms to fill behind a cross wall, two months or even a season will be needed to fill in behind a dam.

At the end of their first and second seasons the dams have to be raised owing to settlement and in order to keep their tops above that of the overflow-channel. At all times both they and the channels have to be watched carefully until they are full and properly settled, as if the channel becomes blocked, or by some means water starts flowing through the dam or over its crest, considerable damage would be done. After the dams have filled up, it is necessary to construct either walls or training banks paved on the interior face, in order to form a well-defined course for the stream across the filled-in area behind the dam; otherwise, the stream flows from side to side over this portion, with the risk that it will scour through the top of the dam and over the front face, with fatal results. Once full and working correctly, the dams give quite good results, but during the rains they have to be inspected frequently, at least once a month.

Design of Deviation-Channels.

Before constructing a deviation-channel, it is important to have a good knowledge not only of the materials through which it will have to pass, the probable sites for training walls, and the place where the water will be cascaded back into the ravine at the end of the deviation, but also of the conditions under which it will have to function. The former data may be obtained by means of test pits and by observing the strata, but information as to the working conditions is far more difficult to obtain.

The size of the catchment-area must first be determined in order to get the probable flow-off; in considering this, the average grade of the catchment-area and the permeability of the soil must be taken into account, as these two factors will largely determine the maximum quantity of water that will flow off the area in a given time, since the steeper the grade and the less permeable the soil, the more the water will tend to flow off in one rush after a heavy downpour. The heavy storms which give the big flows-off are short in duration, and these factors are therefore important.

Following this, some determination of the cross section and the profile of the valley should be made, in order not only to determine the possible grades for the deviation, but also the actual area and grade needed by the flow-off, which gives a useful check on any calculations. The maximum cross section utilized by the flow-off is most easily determined at points where the ravine cuts through some rock formation. Traces of mud, or the level on the sides of the ravine at which grasses and plants may be seen growing, give valuable indications of the probable depth of the flow, especially in the case of ravines carrying mud-runs.

At the same time, some estimation must be made of the class of material that will flow, and of any subsequent changes in its velocity which may be caused by works placed farther up the ravine than the proposed deviation. But, while the aim of the design should be to give the best results after the completion of all the proposed works, the deviation must be built so as to function satisfactorily in the interim; it is usually impossible to complete a series of works in one dry season, and in any case it is probably impracticable to do so until some results have been obtained from the works first put in.

With these details in hand, the two ends of the proposed channel are fixed both in regard to their actual position in the ravine and to their level above its bed, taking into consideration such matters as the approximate grade that will be needed and any good strata in the rock. The entrance should be placed on a site where good foundations may be obtained for the erection of an economical deviating wall, and the exit either at a point where there is a good outcrop of rock over which the deviated waters may safely be cascaded back into the ravine, or at such a point and level where they will occasion the least possible erosion and disturbance to the sides and bed of the ravine.

Following this, the line of the channel must be fixed, which for economical construction means that it must follow as far as possible the contour of the valley side, and from this line the grade is determined. Actually, on the shorter deviations considerable variations of grade may be determined by careful selection of the entrance and exit and their possible levels in relation to the ravine bed, or by alterations in the height of the deviation wall.

Then, before the actual cross section to be used is determined, the question of the class of material that is likely to pass through it must be considered, as, if it is required to pass a flow heavily charged with detritus, it must have a steeper grade and a deeper cross section than would otherwise be necessary, and care must be taken to avoid sharp changes in direction and cross section or

lessening of the grade, as any of these would cause the detritus to deposit and block the channel. Such changes of direction and cross section as are unavoidable for economic reasons must be compensated by manipulation of the grade, but where a heavy charge of detritus is carried they should be as few and as small as possible. With this class of material, observations taken of existing deviations show that the grade should not be less than 20 per cent., and that, as far as is possible, the grade and size of the deviation should not vary greatly from that of the original ravine in the parts where it passes through rock.

If, on the other hand, only water with a small quantity of detritus is to be passed, then the only necessity is that the channel should be large enough to deal with any storm-flow, and that its grade and cross section should be so designed as to keep the velocity of flow high enough to prevent any possibility of its filling up; this velocity should be from about 8 to 10 feet per second. Further, the difference in the "roughness" of the original ravine and of the deviation must be considered and taken into account, as this will affect the velocity of flow.

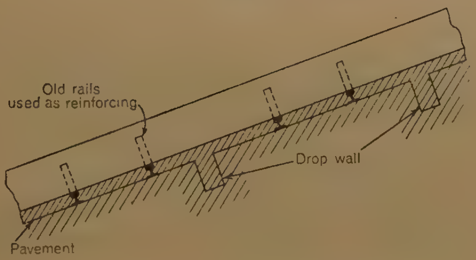
It is seldom necessary that the deviation-wall should be actually built as a training wall, as this would mean a longer and more costly wall. Usually the wall or dam is built normal to the sides of the valley, as in the case of a cross wall, and the detritus brought down during storms will gradually fill in the space behind the wall up to the level of the mouth of the deviation-channel, the wall being rendered impervious by the process. Through this deposit the stream will cut a course, which at this stage is usually artificially defined, by the construction of training walls or banks built on top of the sediment, in order to prevent meandering and to guide the stream to the mouth of the deviation without allowing it to form eddies. If either eddies are set up or the stream meanders considerably, there will be a resultant loss of velocity and material will be deposited, which might cause the channel to silt up and the stream to overflow the wall and do considerable damage.

In the case of paved deviations there is a further consideration to be taken into account, namely, that the steeper the grade the stronger and more costly will the pavement have to be and the more often will it have to be inspected and repaired, in order to withstand the erosion which, in the case of streams heavily charged with detritus, is very considerable. This is due to the fact that the specific gravity of the mud-run is not far below that of the paving material so that the latter, unless it is well secured, is easily carried along with the mud-run. This sets a definite limit to the grade that can be allowed where the deviation will have to pass any form of

mud-run. One of the chief factors in the design of the paving in these channels has been the cost of the transport of the cement from the railway line and of the stone and building sand from the points where these may be obtained. In the case of ravines through shaly or muddy ground, good building sand is very difficult to obtain and the cost of massive pavements is prohibitive.

The chief trouble during maintenance has been that if, during a storm, a small portion of the paving became broken, it usually led, with this point for a start, to a large portion being ripped up before it was possible to make any repairs, while the actual deviation might easily be destroyed. This has led to the evolution of a type of pavement divided into sections and anchored (*Fig. 4*) by placing drop walls at intervals so as to limit the probable extent of the damage. The sections are then further strengthened and divided

Fig. 4.



into sub-sections by placing crosswise in the channel lengths of old 60-pound rail bent into the form of a U and built into the pavement. This type has given excellent results, and generally the damage has been thus limited to a sub-section or, at the worst, to a section.

Calculations used.—As in the case of the cross walls, most of the deviations in use have been designed on site, but the Author puts forward in Appendix III the calculations which he has used as a check on some of the later designs; unfortunately, the amount of practical data available at the time was small and since then he has been employed in other directions and has not been able to elaborate them. The figures taken for the "flow-off" were assumed in order to allow for the worst possible case as, compared with the initial cost of construction and that of repairing any damage due to too small a channel size or slope, the increased cost of installing a channel to cater for all eventualities is small.

Examples.

The works actually in use at certain mud-runs may now be described.

Mollini.—When the line was constructed, this run was quiescent, so no account was taken of it, and the valley was crossed by a five-span bridge, each girder having a span of 5 metres. Shortly afterwards, due to slides which occurred up the valley, the run restarted, thousands of cubic metres of material being brought down after each rain; it either washed away the track at that point or covered it up completely, according to the consistency of the material that had come down. This mud-run was composed of mud, sand, stones and water, and included boulders up to 6 cubic metres in volume. However, although the flow was plentiful and did considerable damage, the run dried fairly quickly, which enabled transhipments of passengers and freight to be made pending the repair of the line.

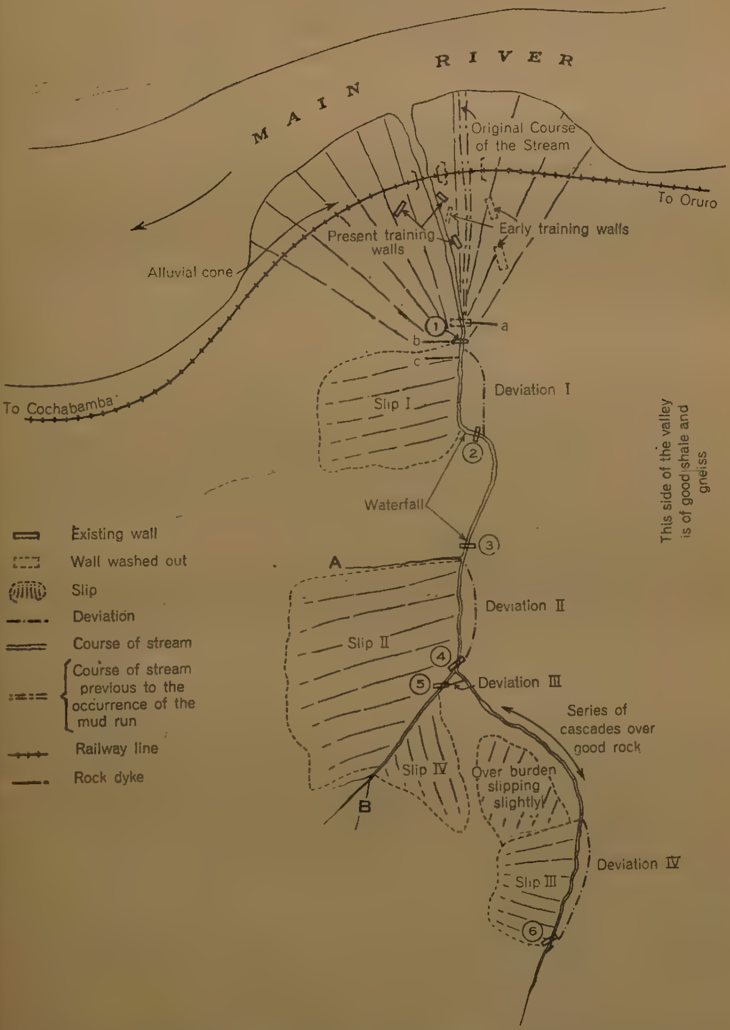
The earliest remedies tried at this point consisted of erecting *chipas* and dry stone walls, in an attempt to guide the detritus through the bridge openings by constricting and localizing its channel of flow, in order to increase the velocity of flow and to keep the detritus in suspension. These works were not strong enough, as most of the larger material brought down by this run was carried by rolling; consequently, they were either broken down or choked up and rendered useless. Following this, an attempt was made to use cross-walls of *chipas* and dry stone work, but, owing to the same reasons, these also were unsuccessful.

Some time later, when the treatment of mud-runs was considered more seriously, a survey was made of the valley in order to discover as far as possible the real cause of the trouble. Starting from the mouth of the ravine, after passing over the alluvial cone (*Fig. 5*), there are, in the first place, three dykes of gneiss. The ravine for the main part runs in a fault line, and these dykes are really harder strata which have been tilted through an angle 85 degrees. The first dyke, "a," in a somewhat shattered condition, appears only as an outcrop on the right-hand side of the ravine; "b," in a good condition, outcrops on the left-hand side and is traceable at least three-quarters of the way across the valley. (No attempt was made to follow it farther, as it dipped steeply and the excavation needed was excessive.) Dyke "c," in a shattered condition, outcrops on the left-hand side.

Above dyke "b" the right-hand bank is formed by a good hard gneiss, but the left-hand bank up to the first bend, where there is a waterfall over the rock, is composed of shattered material and was

slipping badly. Above the fall, the ravine cuts through a fair-grade gneiss until it arrives at the small side branch "A." Above this point the right-hand bank continues in medium-grade gneiss, while

Fig. 5.



the left-hand side between this point and the branch "B," including the left-hand bank of that branch, is composed of an overburden of very badly decomposed shale, which was slipping badly. Above the junction of branch "B," the main ravine passes through

good-quality gneiss and over a series of falls caused by harder strata; the whole overburden between it and the branch "B" was, however, slipping slightly. At the top of these falls, the stream was on the same level as the toe of the overburden and was washing it away and this, in its turn, was causing a bad slide.

After the survey, it was decided to build walls (1) and (3), in order to hold back the slips I and II by damming them against the opposite banks. (Method (2*a*)[1].) This was successful up to a point, as for the first season the walls acted as cross-walls. In the following year, wall (3) was heightened and another wall was built on dyke "a" in order to cover the foundations of wall (1), which were not very deep, against the scour which was taking place as the result of some of the material being held up in the deposits formed by the walls. Unfortunately, during the next wet season, the slide III started to give trouble, and slides I and II commenced to move again because the fillings caused by walls (1) and (3) were insufficient to hold them up; further, the newly-built wall on dyke "a" was destroyed by the mud run, which was again working very actively. It was then decided that, as the right-hand side of the ravine was all on good gneiss, an attempt should be made to deviate the stream over the rock by means of a wall deviating it into a channel cut in the rock; it was then to be allowed to cascade back into the ravine, thus preventing it from washing the slides.

During the first season, as expenditure was limited, a start was made from the top of the valley; deviation IV and wall (6) were constructed round slip III, and a short deviation III was made through the rock at the junction of branch "B" with the main ravine. Wall (5) acted as a deviating wall, in order to throw the water from branch "B" away from slip II. There was a considerable diminution in the flow of the mud-run during the following wet season, but during the next year it was only possible to allow for the construction of deviation II and wall (4). Unfortunately, not only was the work not properly completed before the rains, but, owing to sickness among the staff, the deviations were not efficiently inspected between the storms, with the result that a fall of rock occurred in deviation II; the stream overflowed back into its normal course past the toe of slip II and over all the loose material excavated from the deviation, and this was the cause of considerable mud-runs. As soon as the rains stopped, the work was again put in hand, deviation II was finished off correctly, and deviation I and wall (2) were constructed. During the following rains, which were very heavy, slip IV started and wall (5) was damaged, but

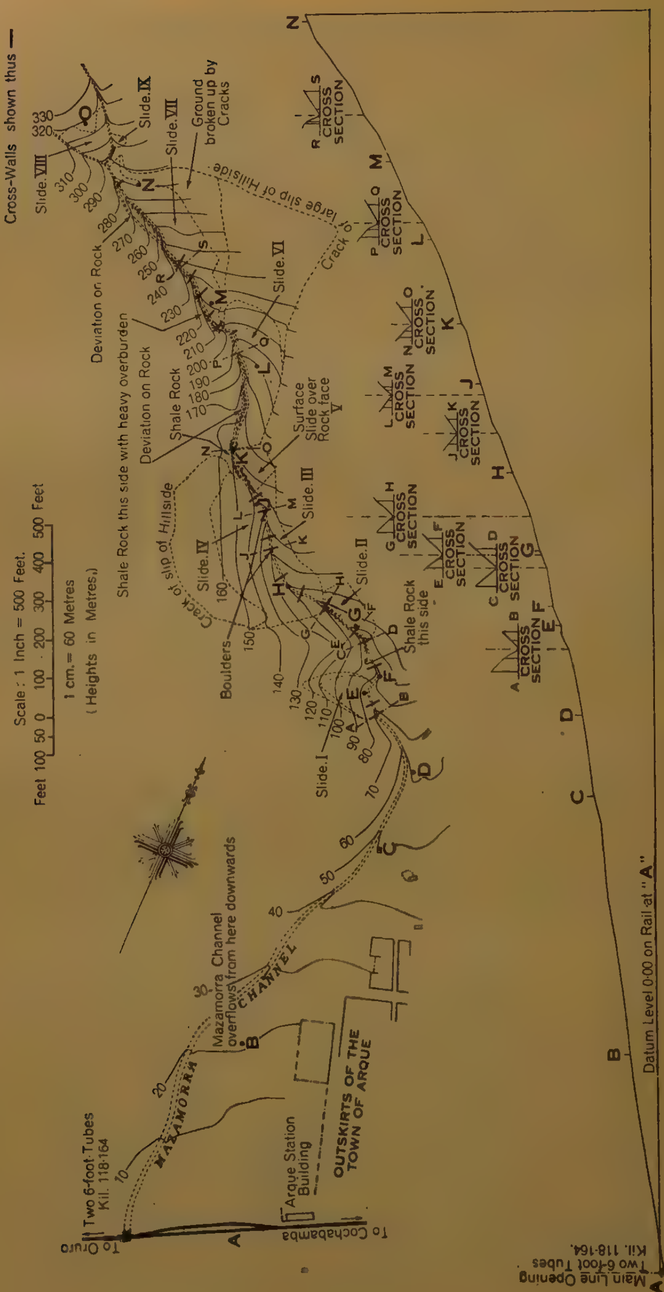
[1] *Ante*, p. 432.

fortunately it was possible to patch it up again between the storms. The whole work of the deviations was so successful that the run gave no further trouble. After the rains, wall (5) was rebuilt and strengthened, but as slip IV was comparatively small no work was done on it; in fact, to a certain extent it is advantageous, as the material brought down by it, while insufficient to cause trouble, is enough to prevent the main river from eroding away the alluvial cone at the mouth of the ravine. Hence, the need for river defences at that point is obviated.

Run at kilometre 118·164.—When the construction reached this point, there was a certain amount of material being brought down the ravine, and it was thought that two 6-foot tubes would be sufficient to overcome the trouble. However, the mud-run was then passing out of the quiescent stage, and the amount of material brought down increased yearly and swamped the station after each big rain. On one occasion the flow was so big that a 25-ton capacity box-car was lifted from the siding and carried bodily some 150 metres over what had been cultivated ground, and deposited in the main river-bed. At first, attempts were made to guide the mud-run through the tubes by digging a channel and keeping this properly cleaned out. These methods were expensive and of no great value, as they did not stop the line from being interrupted after every big storm, so a survey of the valley was then made (*Figs. 6*, p. 446).

Starting from the railway-line, a channel in the alluvial cone leads from the 6-foot tubes; this was kept clean as far as possible. Then slide (1) to the left was supported by a series of two supporting cross-walls. Between slides I and II, as both sides of the valley are of earth, a counter-erosion cross wall was placed. Above this, the left-hand side is composed of poor-grade shale and slide II occurs to the right, the latter being supported by a series of two supporting cross walls. Above this again are slide IV on the left-hand side and, opposite to it, slide III, only separated from slide II by a nose of shale rock. These slides were supported one against the other by a series of seven supporting cross walls, the first of the series being founded on the shale nose. Slide V on the right, and good shale on the left, then follow, and as this slide is comparatively small, it was not treated. Following this, on the right, there is another large slide, VI; here, fortunately, the left-hand side of the ravine is composed of good-class shale and so it was possible to make a deviation-channel over the rock. Next comes slide VII, which is practically a continuation of slide VI, the left-hand side of the ravine being still formed of good shale. Unfortunately, for some distance the overburden on the shale is so heavy that a series of five supporting walls had to be used for the lower portion of this slide. As the

Figs. 6.



PLAN AND SECTION OF VALLEY.

overburden tails off, it was possible to use a deviation-channel for the top portion.

Above this point the ravine branches into two, slide VIII being situated between the branches and slide IX to the right of the right-hand one. The latter slide being small, it has been left untouched. In the case of slide VIII, there was a possibility of the stream being forced by it against slide VII, thus cutting through it and avoiding the top deviation-channel; a heavy retaining wall was therefore built at the toe of this slide to direct the flow of the stream.

The work put in this ravine has been very successful and has already paid for itself. It is especially interesting as it illustrates the methods used to overcome a mud-run of this type, which, while small when compared with those of Mollini, Orcoma, and Arque, gave a considerable amount of trouble, and yearly did a great deal of damage, not only to the station yard but to the town as well. The material brought down by this run was a mixture of shale debris and liquid mud.

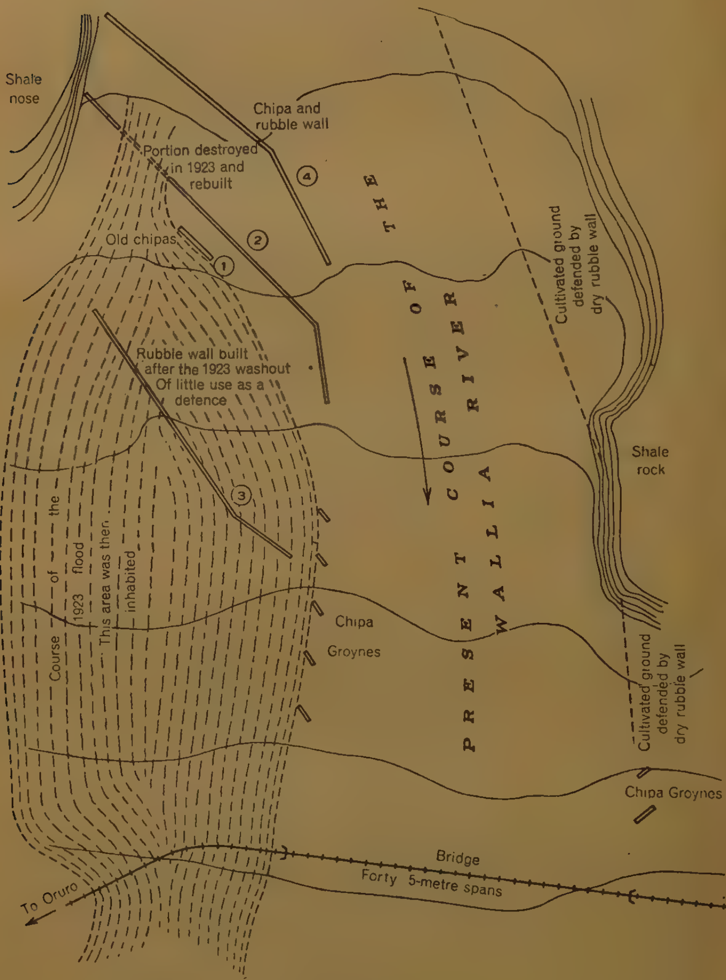
Arque.—This run brings down mud and stones, but no very large boulders. At the time of construction there was a wide river-bed here in which the stream ran in a meandering course channelled by itself, unless it was in flood, when it occupied most of the bed. The town of Arque was situated partly in this bed, and was defended against flooding by native-made defences of dry stone and branches. A bridge of forty spans, each of 5 metres with a headroom of 3 metres, was used to carry the line over the valley.

A year or so after the line was constructed, slides started in the valley and its side ravines, and they have steadily become worse. As a result of this, the flow of detritus, by pushing the alluvial cone out into the main river, raised the bed-level of the latter until, in the first place, the town was blotted out and had to be rebuilt at a higher level, and then the new town had to be defended; finally, the level of the river-bed is now higher than the rail-level of the bridge for three-quarters of its length, and is some 10 metres higher than the level of the main square of the new town. Unfortunately, this level is still rising and now it not only threatens the town, but also the embankments approaching the bridge. In *Fig.* 7 (p. 448) are shown the various defences that have been tried and the attempts made to direct this mud-run.

Unfortunately, the cost of putting in masonry or concrete defences would be prohibitive, and as the townspeople are too indolent to give any serious aid, all the work put in has been of a temporary character. As already explained, at the time of construction the river gave no trouble and little attention was paid to it. The first defences were a few *chipas* (1) which were of no real use. Then,

as the river began to get troublesome, the wall (2) was built with the aid of the townspeople, but in 1923, during a heavy storm, a portion of this wall and part of the town were destroyed. The townspeople

Fig. 7.



then built up a rubble wall (3) in order to divert the river from a portion of the town, but it was of little real strength, and so the *chipa* and rubble wall (4) was built by the railway company. This has since been repaired and then, as the level of the river-bed still

continued to rise, further defences put in with the aid of the townspeople. In 1930 these were again heightened by another course of *chipas* and are, for the moment, effective. However, the mud-run is now more than 3 metres higher on the outside of the defences than the ground-level is on the inside and it is only a matter of time before the defences are overwhelmed, for not only would another course of *chipas* make the whole more unstable, but the lower ones are in a very poor condition and will soon fall to pieces. At the time of writing, the level of the river-bed is higher than the rail-level of the bridge, which is actually now in a cutting in the river-bed for three-quarters of its length.

Orcoma.—The run here is of mud and water in the form of ooze, and is similar to the first example as regards quantities of material brought down by each rain, but in this case the situation was worse as, when the mass was liquid, it was impossible to cross, and it only dried out slowly, forming a crust which was deceptive and dangerous; it was therefore impossible to tranship passengers and goods until either it dried out sufficiently, or was dug off the track. Without a large change in the site and a more expensive location, it was impossible to avoid this run.

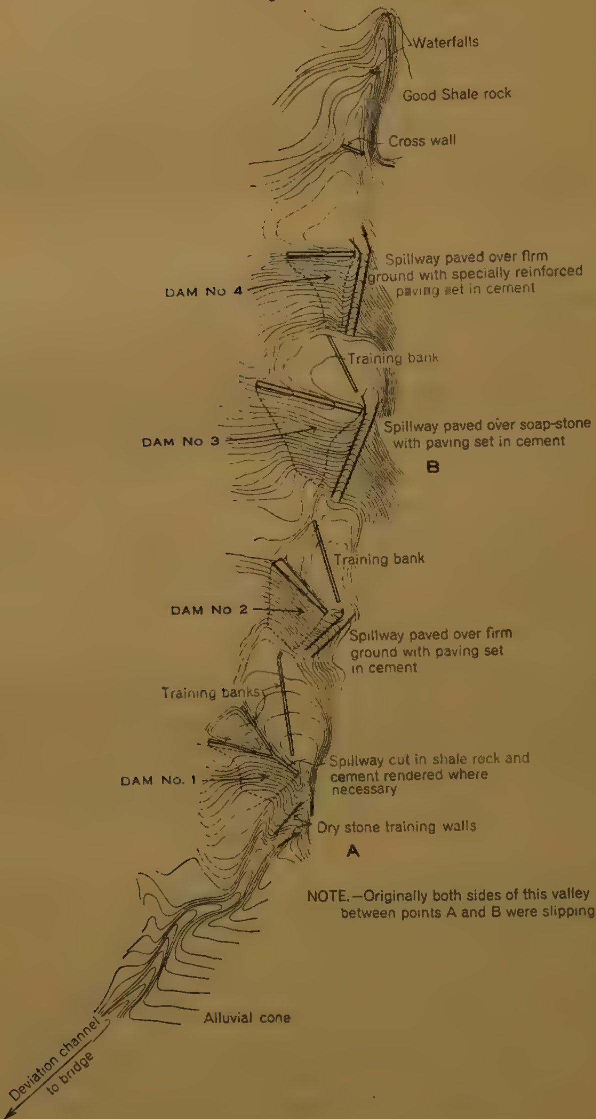
When it was fully realized how much trouble the run was going to cause every wet season, a survey was made of the lower portion, as shown in *Fig. 8* (p. 450). It was found that, for some 500 metres beyond the alluvial cone, and up to the foot of the lowest of a series of waterfalls, both sides of the valley were badly cracked and slipping in, the whole interior of the valley being a soft broken-up mass with a number of springs. The only outcrops were at (A), of poor-grade shale, and at (B) of badly cracked soap-stone. The first attack on this problem was to try to drain the sides of the valley in order to stop the slips; the water was to be carried in flumes, and by the same means the stream was to be prevented from washing against the toes of the slides. Unfortunately, as explained on p. 431, this method was a failure.

After this attempt had failed, the problem of how to deal with this valley still remained unsolved. There was no rock suitable for deviations, and in any case the slides were too continuous for that method; in addition, not only was there no building stone near the site for the construction of a cross wall, but the valley was so wide that the cost of any attempt to bring stone from elsewhere would have been prohibitive. The solution was finally found, and was the construction of earth dams, with paved spillways over firm ground or on rock.

Dam No. 1 was situated in order to make use of the outcrop of shale "A" for a spillway, and it was constructed during the first

season. It proved its value during the subsequent rains, when it filled up with the detritus coming from above, and prevented this

Fig. 8.



from being troublesome; it also arrested the nearby slides. During the next season dam No. 2 was constructed and, as there was no

available outcrop, its spillway was paved over firm ground, while at the same time dam No. 1 was heightened to counteract shrinkage. As these dams gave similarly good results during the next two successive seasons, dams Nos. 3 and 4 were built. Both of these dams had paved spillways, although in the case of No. 3, use was made of the soap-stone outcrop "B." During these seasons, the usual upkeep work of heightening the earlier dams to counteract shrinkage, constructing training-banks on the deposited material, and repairing the spillways, was carried out where necessary, and the system gave excellent results.

Unfortunately, during the next wet season, spillway No. 4 became choked and, before this could be remedied, a cloudburst caused the mud-run to overflow dam No. 4; it destroyed the major part of both this dam and spillway No. 4, as well as badly damaging dam No. 2 and spillways Nos. 1, 2, and 3. As soon as possible, dam No. 2 and spillways Nos. 1 and 2 were repaired, and then spillway No. 3, which was in a bad condition, was widened and made secure again by repaving it and cutting it further back into the soap-stone. Dam No. 4 was then reconstructed, and a spillway cut on a better grade than before. This spillway, which had a length of 80 metres, was paved in cement masonry, as it was both the longest and steepest.

At the same time, the survey was extended up the valley; a large slide on the right-hand bank between the falls, which was invisible from below, was discovered, the left-hand bank being composed of good-quality shale. A series of slides was also discovered on the hillside above the plateau. As the slide between the falls was menacing, it was treated at once, and, since the valley was narrow at this point, stone was collected on the plateau and a type (2*a*)[1] supporting cross-wall was built.

Up to the time of writing, no further works, except for repairs, had been done on this valley, as the quantity of material coming down from the top reaches is not excessive and passes through the spillways and channels and under the railway bridge without causing any appreciable damages.

Photographs of typical examples of cross walls and deviation-channels are reproduced in *Figs. 9, 10* and *11*.

Conclusion.

The methods described in this Paper have proved successful in those valleys which have lent themselves to this type of work

[1] *Ante*, p. 432.

without the cost becoming excessive, that is to say, in those valleys that do not have an excessive number of landslides in their sides and which have not proved too wide for the successful construction of cross walls. The Arque Valley is really a side river and not a ravine, which accounts to a large degree for its intractability, despite the fact that side rivers do not usually give much trouble; by the law of averages, due to their large catchment area, some of their side ravines are quiescent while the others are active, and thus the flow of the mud-run is regulated. In all probability the only remedy here, as far as the railway is concerned, is either a deviation of the line so as to cross the valley higher up at a narrower point and to give it more head-room, or, provided the objections of the townspeople could be overcome, the adoption of the cheaper alternative of constructing an artificial tunnel below the mud-run. Nothing, however, except that the river should again start to scour, can possibly save the town.

The work is still in its infancy, and so far the only runs to be treated have been those that have given considerable trouble and where it has been possible on the analysis of their costs to show a clear saving. Even the older of these works have only been in use for a short time, since the work as a whole was only seriously initiated some ten years ago and has always been hampered for lack of funds. Further, it takes at least four wet seasons to prove that a system of works in a valley is giving satisfactory results, as during the first season very misleading results, that err in either direction, may easily be obtained; the loose debris left over by the construction of the deviations and dams, and the mud-runs of the previous year in the lower reaches, may be brought down and form a considerable run, while, on the other hand, the unfilled spaces behind those walls which were not designed as deposit walls may hold up material that would, as soon as these are full, form a mud-run, thus giving too good an opinion of the works.

There is still considerable scope for experiment and improvements in these methods, and a really scientific study of the causes and behaviour of these mud-runs, as well as the design of the various types of preventive works, should prove very interesting.

The Author wishes to express his thanks to those who have been of assistance to him in the collection of data for this Paper, and to mention in particular Mr. F. F. Williams, a Divisional Engineer to the Antofagasta and Bolivia Railway Company.

The Paper is accompanied by six sheets of diagrams and by eight photographs, from some of which the Figures and the two pages of half-tone plates in the text have been prepared.

Fig. 9.

TRAINING WALL AND DEVIATION CHANNEL AT MOLLINI.

Fig. 10.

CROSS-WALL AT KIL. 94·178.

Fig. 11.

A SERIES OF CROSS-WALLS, WITH LEFT-HAND SIDE OF RAVINE SLIPPING.

APPENDIX I.

Costs for Treatment of a Mud-Run.

DEBIT

Capital Cost	Bs.	*Annual Cost*	Bs.
Cost of proposed works as per detailed estimate, including survey and overhead charges . . .			
Cost of probable extensions needed to river defences, etc., due to main river eroding . . .			
Total Bs. . . .		representing, allowing for interest and sinking fund . . .	
Probable maintenance cost . . .			
* ,, ,, ,, on river defences, etc. . . .			
		Total equivalent annual cost . . .	Bs.

CREDIT

Annual cost of cleaning mud-runs from track . . .	
,, ,, ,, ,, ,, ,, bridges, etc. . . .	
,, ,, repairs to bridges, etc. . . .	
,, ,, ,, ,, track . . .	
,, ,, train delays, transhipments, etc. . . .	
*Probable reduction in main river maintenance costs . . .	
Total annual saving . . .	Bs.

Debit . . .	
Credit . . .	
Balance . . .	Bs.

Usually before starting work, a credit balance of 20 per cent. of the annual maintenance costs has been required.

* These items may be credits or debits.

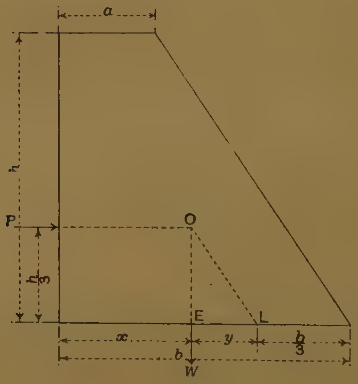
APPENDIX II.

Design of Cross Walls.

Introduction.—Attempts were made to obtain the weight of the mud-run per cubic foot while the run was in action, as directly it stops the water runs off and the density increases; unfortunately, the larger runs are dangerous to approach when in action, so use had to be made of the smaller ones, which are, perhaps, not quite so representative of general conditions. It would appear that 80 pounds per cubic foot is an average weight for a run with an angle of repose of about 8 degrees. As may be expected, the higher the angle of repose the denser the mixture.

Assuming that any benefit that is obtained from the arching of the wall on to the valley sides may be set off against impact and other forces which cannot

Fig. 12.



be determined, then the design of the wall on the assumption that it is a gravity wall, which is filled up to its top with liquid mud-run, but not surcharged, should be a safe one.

Then P, the horizontal force behind the wall, is obtained by using Rankine's Theory for retaining walls (*Fig. 12*).

Let r denote the weight of the mud-run (= 80 pounds per cubic foot).

,, w ,, ,, of the masonry (= 140 pounds per cubic foot).

,, h ,, height of the wall.

,, a ,, breadth at the top.

,, b ,, breadth at the base.

,, Q ,, angle of repose of the mud-run.

,, L ,, angle of surcharge.

Then $$P = \frac{rh^2}{2}.\left(\frac{1 - \sin Q}{1 + \sin Q}\right) = \frac{ch^2}{2}$$

But weight of masonry $= W = \dfrac{w(a+b)h}{2}$,

and
$$\frac{\mathrm{EL}}{\mathrm{OE}} = \frac{P}{W} = \frac{ch}{w(a+b)} = \frac{y}{h/3}$$

and therefore
$$y = \frac{ch^2}{3w(a+b)}$$

For the line of pressure to be in the middle third,

$$x + y = \frac{2b}{3},$$

namely,
$$\frac{a^2 + ab + b^2}{3(a+b)} + \frac{ch^2}{3w(a+b)} = \frac{2b}{3}$$

and therefore
$$b^2 + ab - a^2 - \frac{ch^2}{w} = 0$$

If $a = 0$ or b (the two worst cases) then $b = h\sqrt{\frac{c}{w}}$

From the above
$$c = r \,.\left(\frac{1 - \sin Q}{1 + \sin Q}\right) = 80 \times \left(\frac{0{\cdot}861}{1{\cdot}139}\right)$$

$$b = h\sqrt{\frac{80 \times 0{\cdot}861}{1{\cdot}139 \times 140}}$$

$$= 0{\cdot}65\, h. \text{ approx.}$$

However, taking the worst possible case when the wall fills up to overflowing in the first rain and is thus surcharged with an angle equal to that of the angle of repose,

$$p = \frac{rh^2}{2} \,.\, \cos L \,.\left(\frac{\cos L - \sqrt{\cos^2 L - \cos^2 Q}}{\cos L + \sqrt{\cos^2 L - \cos^2 Q}}\right) = \frac{ch^2}{2}$$

But
$$L = Q.$$

Hence
$$c = r \,.\, \cos Q = 80 \times 0{\cdot}9903,$$

and
$$b = h\sqrt{\frac{80 \times 0{\cdot}9903}{140}}$$

$$= 0{\cdot}75\, h \text{ approx.}$$

These results show that the empirical design is correct, provided there is no large divergence from the weights and angles assumed for these calculations.

APPENDIX III.

DESIGN OF DEVIATION-CHANNELS.

Let R denote the rainfall per hour in metres.
,, C ,, ,, catchment-area in square metres.
,, F ,, ,, run-off factor per hour.

then $$Q = \frac{CRF}{3600} \text{ cubic metres per second.}$$

To allow for maximum eventualities a further factor of safety of $1\frac{1}{2}$ was allowed,

and therefore $$Q = \frac{CRF}{2400} \text{ cubic metres per second.}$$

The factor F varies with the slope of the catchment-area and the permeability of the soil, and its approximate value was determined as follows :—

Slope.	F for permeable soils.	F for impermeable soils.
3 to 1 and above	0·7	0·9
Between 5 to 1 and 3 to 1	0·6	0·8
,, 10 to 1 and 5 to 1	0·45	0·7
10 to 1 and below	0·25	0·5

Let n denote the roughness factor.
,, s ,, ,, slope.
,, f ,, ,, frictional factor.
,, Q ,, ,, quantity of material.
,, A ,, ,, mean area.
,, v ,, ,, velocity of flow.
,, D ,, ,, depth of channel.
,, B ,, ,, maximum width of channel.
,, ϕ ,, ,, angle of repose of the material.
,, p ,, ,, percentage of weight of solid material per cubic metre.

Then as an approximation,

$$v = k\sqrt{\frac{s}{f}} = \frac{Q}{A}$$

and therefore $$v = K\sqrt{\frac{s}{pQnB}} = \frac{Q}{A}$$

Hence, assuming a figure for n for the original ravine and the new deviation channel, it is possible to obtain an approximate figure for the slope required if v is to be constant.

Then $$A^2K \cdot \frac{s}{pQnB} = A'^2K \cdot \frac{s'}{p'Q'n'B'}$$

and therefore $$s' = \frac{s \cdot A^2n'p'Q'B'}{A'^2npQB}$$

In the case of paved channels an attempt should be made to limit the velocity o a small quantity above the critical velocity.

For this the E. A. Moritz formula was used :

$$v = 0{\cdot}6D^{0{\cdot}5}$$

n using this, however, account had to be taken of the minimum flows that arried an appreciable quantity of detritus.

Discussion.

Mr. RAYMOND CARPMAEL said that he had not been faced with Mr. Carpmael. he peculiar problems that the Author had encountered on the Antofagasta Railway ; at the same time, he had had some years of experience of slips on the Great Western Railway. In Britain, as a general rule, the slips were what might be termed conventional, and their treatment followed more or less conventional lines, such as the building of toe retaining-walls, counterforts and so on. Slips of a much more extensive character did sometimes occur, however, and might involve the movement of mountains, particularly in South Wales, where slips involving possibly a million tons of material might and did occur. The problems involved in such cases were very serious ndeed, and were perhaps somewhat akin to those dealt with in the Paper.

He might mention one of his early experiences when dealing with a slip which was blocking one of the Great Western running lines. He was taken down to see it by the permanent-way inspector, and, after one glance at the slip, he began to make his way straight up the hill-side. The inspector called him back, shouting, " It's down here, sir, down here," to which he replied, " I can see the effect, but what I want to trace is the cause." That cause was definitely evident some considerable way up the side of the hill, and was due to an nflux of water. It seemed to him that the Author's real difficulty was to locate and nullify the cause. The immediate trouble in the cases described seemed to be due to the enormous quantities of earth and stone brought down the valleys in times of spate ; it would be altogether impracticable in extreme cases to deal directly with that effect, and the Author had very rightly taken steps to endeavour to deal with the cause, high up in the valleys.

In dealing with nearly all slips the main problem was water,

Mr. Carpmael. and the very first step which had to be taken was to try intercept the water and lead it away from the moving mounta or hill-side. The Author mentioned—and Mr. Carpmael had had t same experience—that his troubles were more acute when heavy ra fall occurred after a period of drought. A slip which had j occurred in South Wales was undoubtedly due to that cause. In th case, the bulk of a moving mountain consisted of Pennant stone, whi was intersected by clay seams. During the prolonged drought last summer, that clay had evidently shrunk; before the clay cou expand and the fissures close in the normal way, the intense heavy rainfall which had been experienced in that part of t country had poured into the fissures and lubricated the clay, wi the result that a whole mountain-side was set in movement. In le obvious cases there might be very thin seams of clay which becan lubricated merely by normal rainfall; it was essential in any ca therefore, that the first step taken should be to deal with the wat

With regard to the particular problems dealt with in the Pap he thought it would be of great interest if the Author would gi particulars of the annual rainfall, the lengths of wet-weather perio and maximum rainfalls in 24 hours, linking that information up, possible, with any particularly aggressive movements. It wou appear that the Author was working on the right lines in trying prevent the erosion of the river-bed, the deepening of the valle and the consequent loosening of the toe of the hill-side, by buildi walls and dams in the bed of the stream. Another of the Autho problems seemed to be the sideways movement of the groun which would tend to close up the valley and shut in the wate The latter problem also confronted railways in England. If sli occurred in a deep cutting, sometimes both sides of the cutti moved. If movements were above rail-level they were compar tively simple to deal with, but, if they were below rail-level, the were generally attended by an actual lifting of the track. Suc problems were very hard to deal with, but perhaps bore litt relationship to those referred to in the Paper.

Dr. Lowe-Brown. Dr. W. L. Lowe-Brown remarked that he had visited some of th railways in the northern part of the Argentine where conditions we somewhat similar to those described in the Paper. In one case a artificial tunnel had been built across a stream about 200 feet wi so that the detritus should be carried overhead, and in order to avo the very difficult foundation problems which would have arisen ha an attempt been made to span the stream with a viaduct. H would like to congratulate the Author on having reduced comparative insignificance the troubles which previously ha apparently threatened the existence of the line, and he felt sure th

those who had to deal with such problems in similar circumstances would learn much from the Paper. Dr. Lowe-Brown.

Since leaving the Argentine Dr. Lowe-Brown had been connected with a very small railway in British North Borneo, one section of which was subject to occasional mud-slides somewhat of the nature of those described in the Paper. In Borneo, however, it rained all the time and the country was covered with tropical jungle, whereas Bolivia was a comparatively arid country with infrequent rains and very little vegetation. In the section of the line in Borneo where the trouble had occurred the railway ran in a narrow gorge; it was simply a pioneer development line, and the amount of traffic made it economically impossible to deal with the problem by methods such as those which might be adopted in the case, for example, of the Great Western Railway, mentioned by Mr. Carpmael. Instead of the streams coming down the comparatively gentle slopes of 1 in 10 and 1 in 6, such as were referred to as existing in Bolivia, they entered the gorge over slopes of 1 in 3, 1 in 1, or in cascades, so that the remedies which had proved so satisfactory in Bolivia were inapplicable in Borneo. Owing to the economic conditions to which he had referred, it was impossible to have a really good location for the line, which had to be placed on the very narrow river-bank just above the normal flood-level; any extraordinary flood was therefore certain to cause scouring and slides. Such slides happened almost every month, but most of them were easily dealt with. Very serious slides did sometimes occur, but, fortunately, only at very long intervals. A very bad flood occurred in 1925 which blocked the railway for a considerable time, but no serious trouble occurred again until 3 December, 1934. On that occasion the slides were the worst that had ever occurred. The rainfall in October had been almost 27 inches, that in November more than 27 inches, and on several days it had exceeded 4 inches. During the first three days of December there were 6 inches of rain at one end of the line and 7 or 8 inches at the other. Those, moreover, were only the recorded rainfalls; no doubt the falls in the interior were much heavier, because on 3 December a flood came down which was 8 feet higher than any previously known. It was quite impossible to get near the line for about a week. The embankments were nearly all washed away over a length of 20 miles, and then the mud-slides came down. One was of 12,000 cubic yards, ranging in height over the line from 10 to 30 feet, while there were others of smaller dimensions.

Colonel Sir Gordon Hearn. Colonel Sir GORDON HEARN remarked that the Author's experiences were somewhat similar to his own when dealing with the problems of the Khyber Railway. The need to reconnoitre an area

Colonel Sir Gordon Hearn.

was well shown by the fact that the side-ravines extended abo 3 miles from the location selected ; some in the Khyber were ev longer, but steps were taken to measure every one of them. Althou the location of the railway had been criticized by the Author, t alternative method of following the contour of the hill-sides out reach of the main stream in the valley appeared likely to result even greater difficulties ; for example, the Potosi–Sucre line, whi was being built in that way, was said to be not yet finished.

There was a tendency, he thought, among Members of T Institution to think that some of those who, like himself, returne from far-distant continents were inclined to tell fairy stories ; fact, however, everything in those continents was on a much larg scale, and the forces of nature were relentless in their attacks engineering works. In the High Andes the soil was evident being denuded and the beds of the rivers were being lowere though it would appear from the Paper that the main stream ha actually risen above the formation-level. He imagined that th condition was only temporary, but it was curious to have a bridg in a cutting. He could not say whether the Author's solution wou be permanent, but in the present phase it seemed likely to b adequate for some years.

In the Khyber Pass some hill-sides were unstable and the detrit fell generally within the Author's first category, shale debris an flakes, but large stones (seldom, however, as large as 4 to 6 cub metres) were rolled along by the swift torrents. The condition described by the Author were more like those encountered in th Eastern Himalayas and in parts of the valley of the Gumal rive on the North-West Frontier. He had no acquaintance with th famous Mud Gorge which lay near Quetta, but possibly other would discuss it.

It might be of interest to give some details of how the torrents i the Khyber were dealt with. In cases where the banks were high deviations were used to reduce the cost of culverts. Those bank had no clay core, such as was shown in *Fig. 3*. It was assumed tha they would be safe from percolation so long as the water was no allowed to rise above the point where a line drawn rising at 1 in from the downstream toe cut the inner slope. An afflux of 1 foo being assumed, the crown of the arch culverts, or, in one case, th bottom flange of the girders was not allowed to be higher than 1 foo below that line. In cases where the bed rose at a slope of 1 in 4 o more, there was no advantage in deviation, and the flow was take through in a bottom culvert. The classical case, showing that th assumption regarding the safety of banks was reasonable, in h opinion, occurred at the Tora Tigga water-course. His calculatio

had shown that some 250 square feet of waterway were required there; but, on representations that perhaps he had under-estimated the amount of absorption in the bed, he consented to its being reduced to about 110 square feet. The flood came down and drowned the bottom culvert completely, the water rising to 15 feet or more above the bed. The water streamed through the bank, which was 40 to 45 feet in height, and rushed through the culvert, but there was no serious damage; the bank stood. The maintenance engineers then increased the waterway, and he did not blame them for doing so. A further example was given by the Louth floods of 1920, when the railway embankment stood perfectly well, although the water ran 20 feet deep or more through a road underbridge. Colonel Sir Gordon Hearn.

He could not say whether any serious damage had been experienced at any opening in the 10 years or so during which the Khyber Railway had been open to traffic; he had, however, been told that there had been some anxiety, owing to the water streaming out near the toe of the bank, but that there had been no washouts. On the other hand, the deviation-channels and culverts were reported to have become silted up owing to insufficient grade having been given to them. He did not consider that the bed-slope of 1 in 20 which the Author recommended was at all excessive for deviations where the detritus was of the nature described. Probably 1 in 40 would have sufficed in the Khyber, because there the larger streams had a bed-slope of only about 1 in 50. He did not attach much importance to culverts becoming silted up to some extent, because the silt was soon blown out.

He made some calculations at that time to see how much water would be held up in the pocket upstream of a bank, but he had kept no figures. Certainly such pockets would be valuable as flood-regulators. He would be inclined to recommend the Author to raise his retaining walls so as to create a pocket of that sort; on *Fig. 3* no pocket was shown. He thought that the Author had taken his deviation-channel rather too high up in the bank, and there was also the possibility that if the Author had made deviation-culverts by cut-and-cover, or by using corrugated-iron tubes, that would have enabled him to create a flood-regulating pocket.

Where every waterway presented its own particular problem, an estimate of the cost could be made only when details were available. He assumed for the Khyber works that the length of the culverts at deviations would be such as would be required for half the maximum height of the bank, and the estimate for the bridging cost had proved to be remarkably accurate. The overhead cost, due to all sorts of causes which did not occur in ordinary work,

Colonel Sir Gordon Hearn.

was perhaps more than was expected, and it might have been better to take one-third of the height for determining the length of barrel; the advantage of such deviation-culverts was, however, shown by the fact that, taking an average figure from three large works, their cost was about one-third of that of bottom culverts. They had, of course, to be made of larger area than high-level culverts, due to the lower velocity of approach.

Every care was taken to get good ground for the deviations, and a free outfall, clear of the toe of the bank, was always insisted on. He wondered whether the Author had considered the possibility of carrying the outfall of a deviation over the intervening spur into the adjoining ravine, or even possibly terminating it on the spur itself. In the Khyber the deviations had been cut through—in one case tunnelled through—the spurs; in another case he had proposed a super-passage, but that had proved to be unnecessary, because a slight re-alignment took place which brought that particular torrent over a tunnel. As the Author remarked, the construction of a paved deviation-bed on a slope was not at all an easy matter. In at least one culvert in the Khyber stepping-down was used. Care was taken to see that the area of the culvert at the steps was not reduced below the theoretical area required for the discharge.

One of the problems still to be determined was whether a culvert was equally effective if it were considerably longer than normal, or whether an additional area should be allowed. For a free outfall there would be some reduction in water-area; possibly, however, the increase of the surface slope might counteract the reduction in the hydraulic mean depth. He believed that great trouble was experienced with large deposits of silt in siphons under the Upper Jhelum Canal. Siphons should certainly be avoided in cases where the conditions were such as the Author described.

The dimensions of the cross walls calculated in Appendix II of the Paper seemed to be fairly correct empirically, taking into consideration the fact that the material had not been, and perhaps could not be, disposed to the best advantage by battering the downstream face. At the same time, he doubted whether the Author's factors were all reliable. The weight of 140 pounds per cubic foot assumed for a dry stone wall seemed to be over-estimated. Again, the weight assumed for the material retained showed that it only contained a little over 20 per cent. of solids.

With regard to the question of discharge, which was dealt with in Appendix III, he would draw attention to a Paper of his own

[1] "The Effect of Shape of Catchment on Flood-Discharge." Minutes of Proceedings Inst. C.E., vol. ccxvii (1924), p. 267.

Colonel Sir Gordon Hearn.

in order to deprecate the Author's method of estimating rainfall-intensity by taking a period so long as 1 hour in the case of a small, steep catchment. He noticed that the Author allowed a factor of $1\frac{1}{2}$ for what he called "maximum eventualities," and possibly that allowed for the shape of the catchments, which certainly appeared to justify such a factor. He was not familiar with the E. A. Moritz formula referred to by the Author, and would welcome some elucidation of it, with some account of the modifications which the Author had found desirable to allow for the detritus in suspension.

Mr. Gribble.

Mr. Conrad Gribble said that most engineers who had to deal with railway work in England had had anxious moments from time to time on account of slips, which generally occurred in clay cuttings and embankments, but which were not due as a rule to existing water-channels but rather to a lack of drainage in the earthworks. The essence of that problem, as Mr. Carpmael had said, was to get rid of the water. In the countries abroad of which such graphic accounts had been given that evening, however, the railway had to be carried safely over watercourses which, though they might be dry at certain periods of the year, at others were raging torrents of water mixed with a large amount of detritus. He wondered how far the precautionary or curative measures which the Author described could be considered to be permanent; according to the Author's own description, it was possible temporarily to divert or control the flow of material down the ravines, but it formed cones and heaps which in time were washed away, and it would appear that all that the Author could hope to do was to keep those forces of nature in control to a certain extent. It seemed hardly possible to carry out any works which could be considered as permanent remedial measures, but in designing new railways in such a country the only safe plan to adopt would be to carry the line over the ravines by means of bridges wide and high enough to allow of the free passage of the floods.

Mr. Williamson.

Mr. James Williamson remarked that in one instance he had had to assist in investigating a river-problem which arose from very similar conditions. The river, one of the north-eastern flowing tributaries of the Danube, rising in the Alps, carried huge quantities of gravel, which had to be kept moving in order to regulate it. He took the opportunity of finding out what was done in the upper regions of the river to reduce the quantity of debris brought down. Curiously enough, in the streams and ravines which gave rise to the greatest proportion of debris he found that a technique had been developed which was almost the same as the step-by-step type of masonry-wall regulation described in the present Paper. At first sight it might seem that that sort of regulation would only be

Mr. Williamson. temporary, but on further examination it would appear that with suitable construction it had a considerable measure of permanence for the following reason. When a series of masonry walls was formed the first effect was to trap debris by the separate walls. Thereafter provided the walls were substantially founded and substantial in themselves, there was effected a considerable flattening of the gradient, and the bed had been widened. The same quantity of water had still to be taken, but it was flowing in a wider and shallower channel and with reduced velocity, so that erosion at the sides of the channel itself, which was one of the main factors in bringing down material, was largely eliminated.

*** The Correspondence on this Paper, together with the Author's reply, will be published later.—Sec. Inst. C.E.

EXTRA MEETING.

9 July, 1935.

SIR ALEXANDER GIBB, G.B.E., C.B., Vice-President, in the Chair.

SPECIAL LECTURE ON

"Italian Docks and Harbours."

By Professor HENRY COEN CAGLI, M. Inst. C.E.

TABLE OF CONTENTS.

INTRODUCTION.

THE problems of the construction, maintenance and working of ports are, for Italy, of especial importance, as a result of certain geographical and structural features of the country; these, on the one hand, have led to the necessity for very numerous ports, and on the other hand, have made their study very difficult, and, in the majority of cases, their construction very costly.

Italy, with its 8,500 kilometres of coast-line compared with 1,920 kilometres of Alpine borders, and with an area of 410,000 square kilometres, can be considered rather as an island than as a peninsula, the proportion of coast-line to territory being 1 kilometre length for 36 square kilometres in area, as compared with the following figures for other countries:

Great Britain	1 to 16·4
France	1 to 111·3
Germany	1 to 151·0
Spain	1 to 144·3

The result of this high proportion of coast-line to territorial area is that the greater part of the foreign commerce of Italy must necessarily travel by ocean routes, and hence through the various ports. In addition, the lengthened shape of the peninsula, its most pronounced mountainous conformation, which renders particularly difficult internal communication by road—especially between the Tyrrhenian sea and the Adriatic—and also the inadequacy of river-transport, have developed sea-routes for internal exchanges between various towns.

On account of these characteristics of the coast, sparsely endowed with naturally protected and adaptable harbours, and the hydrographical features of the sea, which is almost tideless, Italian ports are nearly all artificial and built outside the coast-line; that is, constructed to enclose a greater or lesser sea surface by means of artificial breakwaters of great size. There are a very few ports, almost exclusively used by the Royal Navy, such as Spezia, Taranto, Augusta and Pola, which have been adapted from natural roads, and there are numerous minor ports situated in the lower waters of certain rivers. There are, however, only two examples of internal ports, that is, ports excavated inside the coast-line: Port Marghera at Venice and the new port of Leghorn.

Under such circumstances, outer harbour-works assume a very great importance in Italy, and consequently it is easily understood why they have constantly formed an object of particular study and why they present the most varied forms in relation to the various characteristics of the different localities. Very often, on account of the conformation and nature of the coast which, in Italy, consists largely of sandy beaches, the ports must be protected not only against storms but also against silting up wherever the littoral drift is pronounced.

There are about a hundred ports under the administration of the State, as well as numerous others, of lesser importance, under the administration of their respective municipalities; their number, combined with the small traffic at many of them as the result of their limited hinterland, and conversely the remarkable technical and economic importance, in almost all cases, of their works, explains why, notwithstanding the care taken for the improvement of the ports, such improvement was not, until about 30 years ago, sufficient for the needs of the country.

In the immediate pre-war period of 1913, Italian maritime traffic had reached the totals of three-and-a-quarter million passengers and 32,000,000 tons of merchandise loaded and unloaded annually at all the ports of national importance; in spite of this, only 27 kilometres of wharves were provided which were useful for commercial operations, and approachable by ships of a medium or heavy tonnage. Of this total about one-half were still unprovided with railway sidings and any kind of equipment, whilst the remainder were provided with little more than two hundred mechanical devices for the loading and unloading of goods.

Nor did the situation noticeably improve when the depression of the years immediately following the war (in 1920 the mercantile traffic was reduced to 18,500,000 tons) was followed by a revival of trade with a rapid increase in the tonnage handled, which brought

the total, in 1929, to little less than 39,500,000 tons of goods. Rather, it can be said that, even with the reduced commercial trade, the deficiencies had become, about the year 1920, still more noticeable, especially on account of the enormous progress which had taken place in naval construction with the entry into service of cargo and passenger ships larger and faster than their predecessors.

The Fascist Government immediately took into account the urgent necessity for improving the conditions of the maritime ports so that they should not be deprived of those types of international trade which, revived by social and political peace, gave signs of rapid development. However, with the object of achieving the maximum results with the means at their disposal, the Government wished above all to satisfy the needs of the leading ports, as representing the real driving-forces of the economy of maritime transport, without neglecting the lesser ports.

In this manner, in little more than twelve years after 1922, the leading ports have made really satisfactory progress. The port of Genoa has been completely renovated as regards its old accommodation, and considerably extended by the creation of new commercial basins. The result has been that its possibilities have been doubled by means of considerable works and facilities, which have meant an expenditure of more than 400 million lire. The port of Leghorn has also been improved and extended by the excavation of new internal basins, provided with an industrial zone, at a cost of nearly 85 million lire. The harbour of Naples has been completely remodelled by the creation of new basins and the construction of particularly important works, such as a new maritime station and a large graving-dock. A grant of about 300 million lire for this work has now been very largely spent. The old port of Venice has been considerably improved, and a new commercial and industrial port has been created, necessitating the expenditure of a sum of little less than 200 million lire for the harbour-works alone, at the expense of the State. At Trieste many of the old works have been consolidated, and the port facilities have been completed with the expenditure of 150 million lire.

While these are the principal achievements, many other provisions have enabled the condition of several other minor ports to be improved. The results of these few years of hard work are shown by the following figures: eighty-five ports have been greatly improved; more than 33 kilometres of protective outer works, frequently of great size, have been erected to shelter about 700 hectares of new basins; about 40 kilometres of quays, in water of varying depths, have more than doubled the berthing-frontage available for commercial purposes, while the land available for

factories and warehouses within the ports has been increased by 300 hectares. The ports, as regards facilities and equipment, have also been renovated: more than two hundred new machines for the loading and unloading of goods have been installed; new transit-sheds and warehouses over an area of about 100,000 square metres, and several large wharves for the landing of passengers, have been constructed, such as those at the ports of Genoa, Naples, and Trieste, which, until 10 years ago, had very little accommodation of this type; new dry-docks for ships of the largest tonnage are either under construction or completed; finally, the depth of the harbours has been improved by means of a total volume of dredging of about 20,000,000 cubic metres. All these works have been executed in the last 12 years, at an expense of little less than 2,000 million lire.

In the next portion of the Lecture I shall describe briefly the leading Italian ports, and then I shall touch upon their special features, dealing more particularly with the evolution that has taken place, in Italy, in the field of outer protective works—which have to be considered as the most important of all harbour-works—and with the latest studies carried out in Italy on this subject.

Summarized Description of the Leading Ports.

(1) *The Port of Savona*, situated on the western shore of the Ligurian Gulf, owes its significance to the import of coal. A particular feature is a special wharf for unloading coal, connected with a rope-way 18 kilometres long, allowing the transport of 1,200,000 tons of coal yearly from the port to the San Giuseppe railway station, beyond the Cadibona Pass on the Apennines, 300 metres above the sea.

(2) *The Port of Genoa* (Figs. 1, Plate 1), on which much information has been given by my friend and colleague, Dr. Brysson Cunningham,[1] has been improved to a very great extent in the last few years. Its total traffic has reached, in 1928, a maximum of about one hundred and fifty thousand passengers and 8,500,000 tons of goods.

Mainly exposed to the storms coming from the south or south-west, with waves exceeding 6 metres in height, the harbour is at present protected by three outer works, namely the Prince Umberto and Galliera moles, nearly parallel to the coast and having a length of about 4,700 metres, and two secondary breakwaters; the latter are the lee breakwater and the Umberto Cagni mole, forming the boundaries of the port on the western and eastern sides respectively.

[1] *Engineering*, vol. cxxxix (1935), p. 133.

The whole water-surface enclosed is about 349 hectares, subdivided into four principal basins. (*a*) The outer harbour, with depths of from 10 metres to 20 metres, in which are a small basin for the reception of pleasure craft and a group of three dry docks, close to which a fourth one, 350 metres long, 40 metres wide and 12·50 metres deep on the entrance sill, is now under construction. (*b*) The old inner harbour, in depths ranging from 10 metres to 12 metres. (*c*) The Victor Emmanuel III Basin, communicating with the outer harbour by means of an opening 100 metres wide through the Galliera mole. (*d*) The Benito Mussolini Basin, to the west of the previous basin. Both the latter basins have minimum depths of 12 metres. The inner harbour is bordered by about 10 kilometres of quays, equipped with one hundred and twenty cranes of various lifting-powers and adjoining 52·5 hectares of available land. In the centre of this basin two piers provide very extensive accommodation for overseas passenger traffic. The Victor Emmanuel III Basin, specially intended for coal imports, affords 3,170 metres of berths, equipped with forty elevators allowing a discharge of 50 tons of coal per hour each, and provided with 38 hectares of available land. The Benito Mussolini Basin will include, when it is finished, five large jetties with a total of 5,300 metres of quays and 75 hectares of land.

A system of electrified railway sidings connects all the quays with the different trunk lines, to which there will be shortly added a main trunk road, 50 kilometres long, joining the port with the two main roads in the Po valley, from Serravalle Serivia towards Turin and Milan.

The quay walls are generally of the artificial-block type, except for a few short sections of quays constructed under compressed air or with reinforced-concrete caissons filled with pozzuolanic concrete. The outer protection-works are of the mixed type, with a vertical wall of cellular or cyclopean blocks, founded on a rubble mound, except for 800 metres of the old Galliera mole, which has a structure of the sloped type.

(3) *The Port of Leghorn* (Figs. 2, Plate 2) consists at present of two adjoining harbours: (*a*) the old Mediceo Port, covering a water-area of about 42 hectares, enclosed between two converging moles—the Mediceo mole and the straight breakwater (*Diga Rettilinea*)—protected on the south by the Vegliana breakwater (*Diga della Vegliana*) and sheltered against the prevailing storms from the south-west by the curved breakwater (*Diga Curvilinea*); (*b*) the new port, excavated within the shore-line to the north of the old port, with a total water area of 45 hectares 9 metres deep, opening into an outer harbour covering a surface of 22 hectares. This new harbour is protected on the north by the Marzocco breakwater (*Diga del

Marzocco), and on the south-west by the Meloria breakwater (*Diga della Meloria*).

The old harbour, which, in 1929, had to deal with a maximum traffic of 2,150,000 tons of goods, is provided with 4,500 metres of quays, having a maximum draught of water of 8·50 metres, and is equipped with four coal-elevators, twelve electric cranes and a special transporter, of 30 tons lifting-power, for loading marble. The new harbour, capable of further extension, is at present provided with 1,800 metres of quays founded 10·50 metres below sea level and 1,300 metres of quays in a depth of 4 metres specially intended for inland navigation. Two special inner basins are annexed to the new port, one for the landing of mineral oils and the other reserved for naval construction. An industrial zone covering 100 hectares, served by a canal 9 metres deep, adjoins the new harbour. The two harbours are joined together by means of inner canals in connection with a canal joining Leghorn with Pisa. They are provided with a total of 60 hectares of land for commercial purposes.

The quay walls of the old harbour are generally of the artificial-block type; those in deep water and in the shallow water of the new port are, respectively, of the well-foundation type and of reinforced-concrete sheet-piles. The protection works are all of the sloped type, with a structure of rip-rap artificial blocks in the curved breakwater (*Diga Curvilinea*), and of plain rubble, or of rubble faced with artificial blocks, in the others.

(4) *The Port of Civitavecchia* owes its importance to its proximity to Rome and to its functions as a terminal for maritime communication between continental Italy and Sardinia.

Since the end of last century, the old Roman port has been thoroughly remodelled and extended, and at the present date important works are in hand for the further extension of the port, comprising the construction of a new commercial basin, the lengthening of the main breakwater, and the construction of new quays in deep water in the old basins.

(5) *The Port of Naples* (Figs. 3, Plate 3) owes its great importance, besides its trade in merchandise, which reached in 1928 a maximum of 2,670,000 tons, to its exceptional passenger traffic, which is larger than that of any other Italian port, and which reached a maximum of one million, three hundred-thousand passengers in 1925.

Mainly exposed to the storms coming from the south-west, with waves which rarely exceed 4 metres in height, the harbour is protected by a succession of outer works, having a total length of about 4 kilometres: the San Vincenzo mole, recently extended by a new detached arm; the outer wall (*Antemurale*), leaving an entrance 300 metres wide between its southern head and the new arm of the

San Vincenzo mole, in from 35 to 42 metres of water, facing the east-south-east; and the Granili breakwater (*Diga ai Granili*), running from the northern extremity of the outer wall (*Antemurale*), parallel to the shore, and affording another entrance to the port, in from 10 to 20 metres of water, facing the south-east. These two entrances lead to a main outer harbour, having a surface-area of about 90 hectares, and to an easterly auxiliary outer harbour, having a surface of about 28 hectares.

Five distinct basins are provided for commercial movement: (*a*) The Beverello Basin, with a water-surface of 20 hectares 12·5 metres deep, enclosed between the first arm of the San Vincenzo mole and a large jetty parallel to it, used by the largest ocean liners. (*b*) The old mercantile port, covering a water-area of about 50 hectares from 4 to 13 metres deep, having in its central part a trapezoidal jetty providing accommodation for the national mail service. (*c*) The Graving-Docks Basin, of about 6 hectares of water-surface 11 metres deep, serving both the maritime traffic and two existing dry docks, in addition to which a third and larger one, with a double entrance, 321 metres long, 40 metres wide and 13 metres deep on the entrance sill, is now under construction. (*d*) A special basin for timber and coal traffic, with a water-area of 15 hectares 11 metres deep. (*e*) The new mercantile port, with a water-area of 50 hectares from 10 to 20 metres deep. The whole of the port is provided with 8,000 metres of quays, all served by railway sidings and equipped with four coal-elevators and thirty-five electric cranes of various lifting-powers.

The quay-walls are generally of the artificial-block type, with the exception of a few sections of new quays of the caisson type, founded in some cases by compressed air. The San Vincenzo mole is of the old rubble sloped type with a facing of artificial blocks, while all the other outer works are of the mixed type, having the vertical wall formed, in the case of the outer wall (*Antemurale*), by ordinary artificial blocks, in the case of the Granili breakwater (*Diga ai Granili*) by cellular blocks, and in the case of the new arm of the San Vincenzo mole by cyclopean blocks.

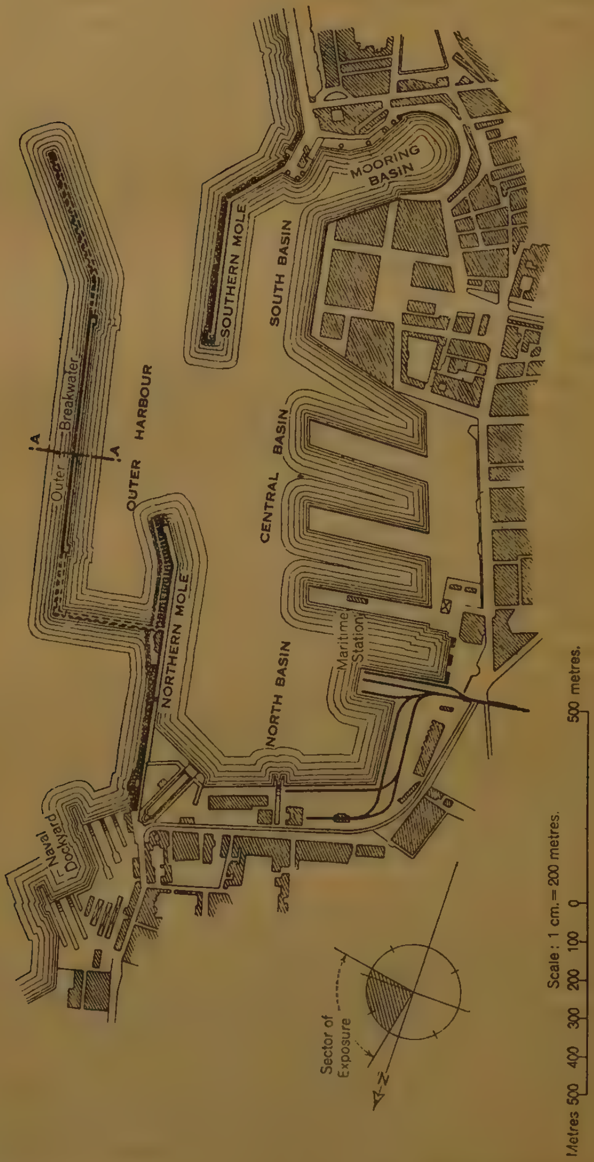
(6) *The Port of Cagliari*, situated on the eastern coast of Sardinia, covers at present a water-area of about 100 hectares, but the commercial basin is still confined to the innermost part of the harbour, covering only 34 hectares of water-surface.

The layout of the remaining area, intended to form a new commercial basin, has not yet been designed; but a small harbour has been constructed on the south-east of the present commercial basin, for the loading of salt from the adjoining salt-marshes.

(7) *The Port of Palermo* (*Figs. 4* and *5*, pp. 472 and 473), which is

exposed to winds from between north and east, covers a water area of 96 hectares, sheltered by two converging breakwaters known as the

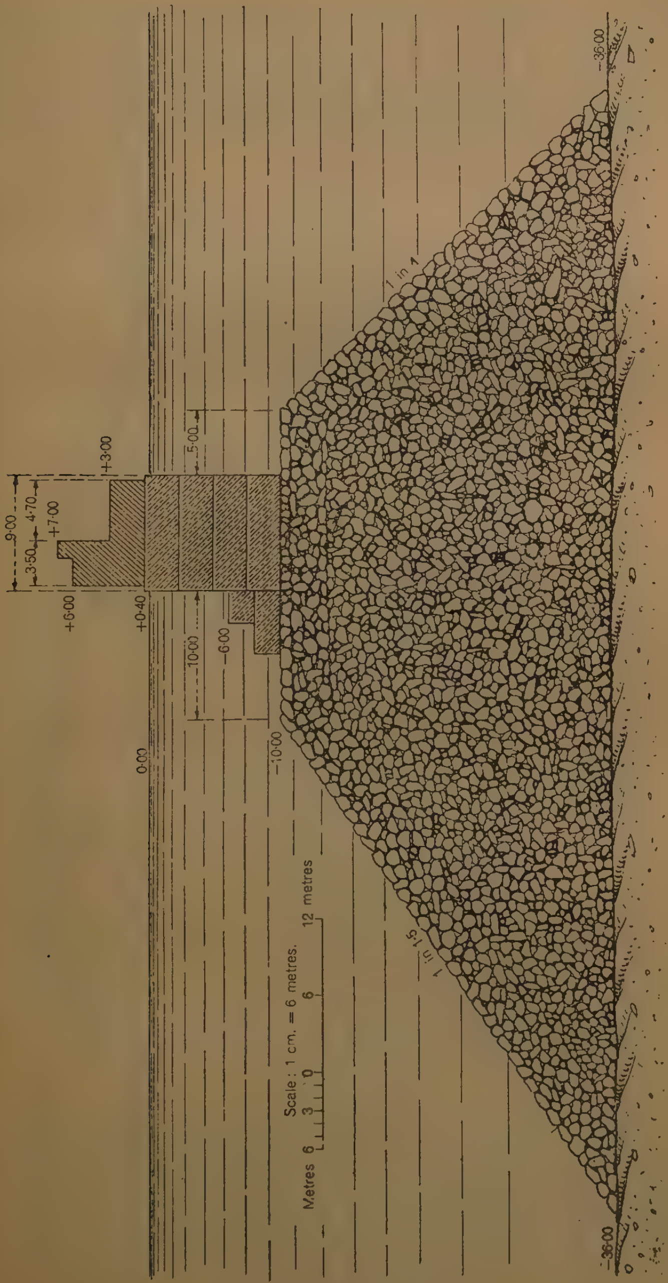
Fig. 4.



PALERMO.

north and south moles, and by an isolated breakwater called *Diga Foranea,* affording two entrances facing respectively the north and

Fig. 5.



PALERMO: SECTION AT AA OF OUTER BREAKWATER.

the south. Works are now under construction in order to close the north entrance and to protect the south one in a more satisfactory manner by lengthening the breakwater towards the south-east.

The whole water-surface is divided into three basins: the North Basin, in depths ranging from 7 to 10 metres and provided with

Fig. 6.

CATANIA.

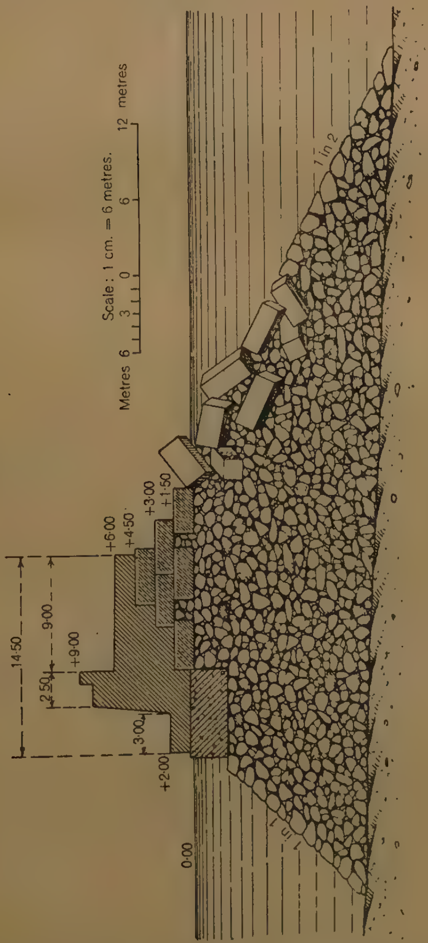
1,500 metres of quays; the South Basin, with a mean depth of 7 metres bordered by 1,500 metres of quays; and the Central Basin, 9 metres deep, equipped with 1,800 metres of quays.

In all, this port, which had to deal with a maximum traffic of about one hundred and seventy-five thousand passengers and 1,127,000 tons of goods in 1930, is provided with about 2,000 metres

of quays in deep water, and 20 hectares of embankments, and is equipped with fourteen cranes having a total lifting power of 48 tons.

The north and south moles are of the sloped rubble type, while the outer wall, running in depths from 35 to 40 metres, is of the mixed type with a wall of cyclopean blocks. The quay walls in deep

Fig. 7.



Catania : Section at AA of East Mole.

water were partly constructed under compressed air and partly of the usual type with artificial blocks.

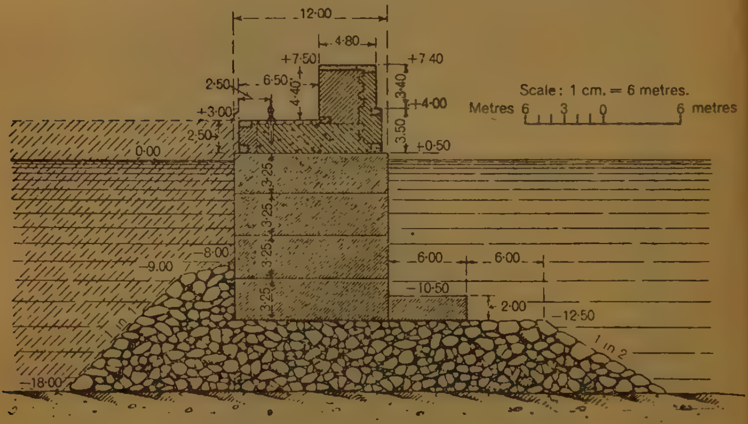
(8) *The Port of Messina*, on the western coast of the Messina Channel, consists of a very deep natural basin of about 82 hectares water-surface. The harbour is of particular importance as a terminal for the ferry-boats which cross the channel regularly.

Many old quays had to be reconstructed after the earthquake of 1908, and some new ones, in deeper water, are now under construction on special anti-seismic lines.

(9) *The Port of Catania* (*Figs. 6, 7, 8* and *9*), situated on the eastern coast of Sicily, is mainly exposed to winds from between east and south-east which, blowing over a fetch of more than 900 miles of open sea up to 4,000 metres deep, may cause very violent storms, with waves exceeding 7 metres in height.

The harbour consists of an artificial basin with a water-surface of 66 hectares, protected by a main east breakwater running from north to south with a total length of 1,860 metres, and by a return south breakwater, leaving between its head and the inner front of the east mole an entrance 250 metres wide, and from 10 to 16 metres

Fig. 8.

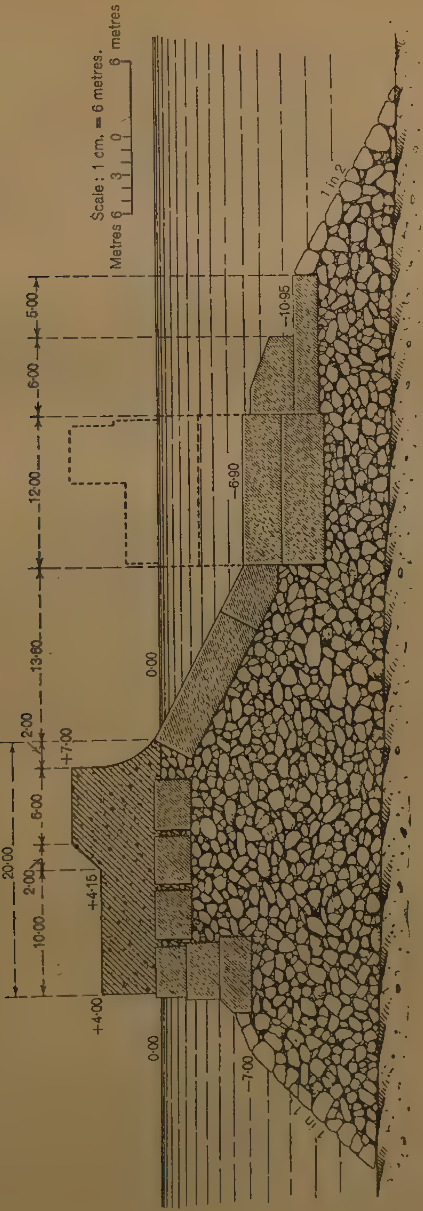


Catania: Section at BB of East Mole.

deep, facing south. In the inner basin there are 3,000 metres of quays with a depth of water of from 7 to 10 metres, provided with 15 hectares of land. The traffic of the port had reached, in 1934, a maximum of 700,000 tons of merchandise.

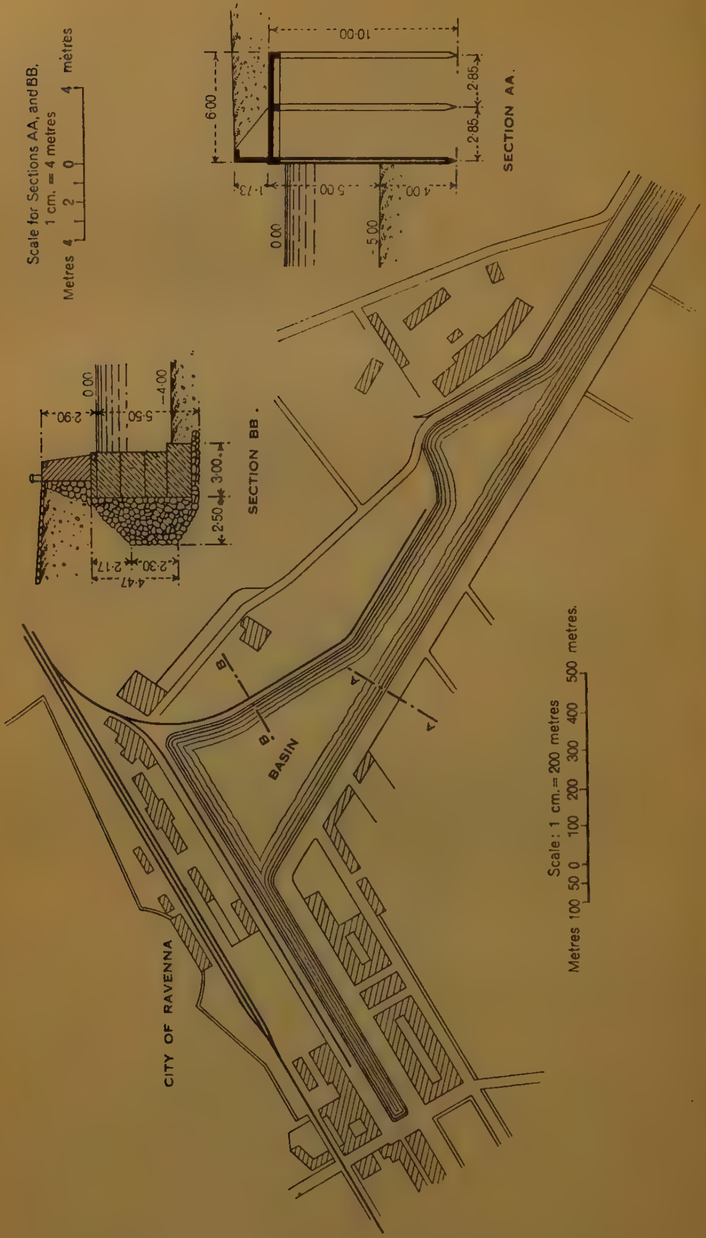
The structure of the east mole is, in its old part 1,120 metres long, of the rubble-mound type faced by artificial blocks deposited pell-mell; its remaining length had been designed, and was for a great part actually constructed, on the mixed type, but it was destroyed by a terrific storm on 26 March 1933, and is now under reconstruction in the rubble sloped type. The south mole is also of the sloped type, and the quay walls are of the artificial-block type.

Fig. 9.



CATANIA: SECTION AT CC OF EAST MOLE.

Figs. 11.



RAVENNA.

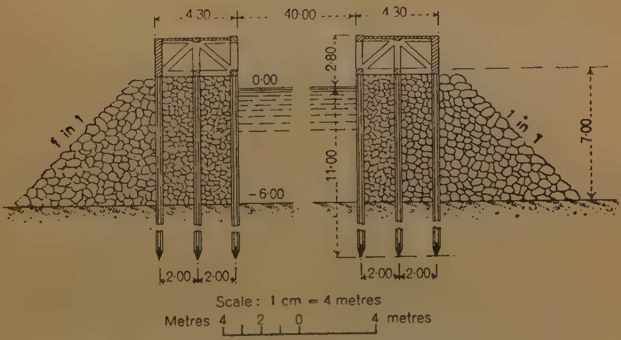
(10) *The Port of Bari* (Figs. 10, Plate 3), situated on the Adriatic coast, has a particular significance through the advantage of its geographical position, enabling it to be an important terminal for sea-traffic between Italy and the Near East.

In view of such a favourable situation, the old port has been extended to a water area of 230 hectares, of which the first section of the new quays in deep water is now under construction.

(11) *The Port of Ancona* is the only important landing place in the middle Adriatic. It consists of an artificial basin of 70 hectares water-surface enclosed between two converging moles, which are now to be lengthened in order better to protect both the entry and exit of vessels, and ensure the smoothness of water in the inner basin.

(12) *The Port of Ravenna* (*Figs. 11* and *12*). The only important

Fig. 12.



PORT OF CORSINI: SECTION AT ENTRANCE TO CANAL.

example, in Italy, of a seaport situated inside a channel—the traffic of which reached in 1931 a maximum of 430,000 tons of merchandise—owes its efficiency and its depth of about 5 metres to the existence in the vicinity, and in direct communication with it, of certain lagoon marshes, called *pialasse*, which store the sea-water during the flood-tide and return it to the sea during the ebb-tide. The local mean range of the tide being 0·74 metres, this serves to maintain the excavated channel.

The port consists of three parts, namely: the *Darsene*, or basins, near the city of Ravenna, with a water-area of 3·6 hectares; the Corsini canal, 10 kilometres long, between the city and the sea, having a surface of 43 hectares, and the harbour at its mouth, called the port of Corsini, covering a water-area of 8 hectares. The harbour entrance is formed and protected by two parallel moles, 40 metres apart, which stretch seaward in the east-north-east direction for a length of about 600 metres, the depth of water being 5·50 metres at

Fig. 13.

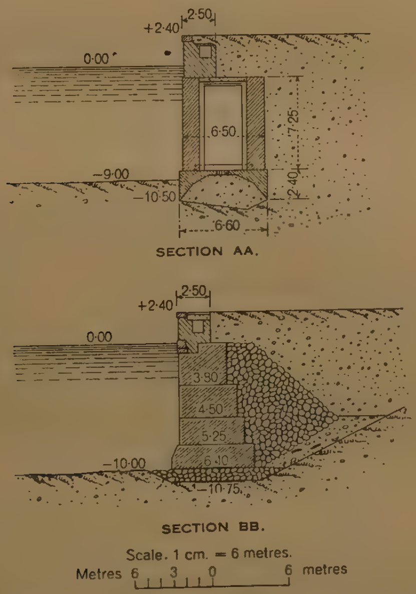
VENICE (PORT MARGHERA).

their extremities. The quays available for commercial purposes have a total length of 2,610 metres, of which 1,520 metres are in the Ravenna Basins and 1,090 metres are at the port of Corsini.

The structure of the moles is of the cofferdam type, partly of timber and partly of reinforced concrete, filled with rubble and protected on the outer side by a rubble apron. The quay-walls are partly of masonry or artificial blocks founded on timber piles, and partly of reinforced concrete.

(13) *The Port of Venice* (*Figs. 13, 14* and *15*), with a traffic of

Figs. 14.



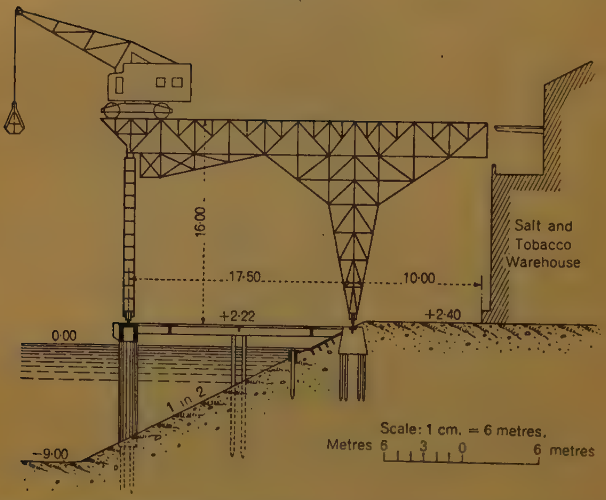
VENICE (PORT MARGHERA): SECTIONS AT AA AND BB OF QUAY-WALLS.

fifty-seven thousand passengers and 3,730,000 tons of merchandise in 1934, ranks second amongst the Italian ports after Genoa, and it may also be considered to be of particular importance with regard to its physical, hydrographical and technical characteristics, which make it quite different from all the other ports. The port, as is well known, is situated inside the historical Lagoon, covering a surface of 58,660 hectares and communicating with the open sea by the three mouths of Lido, Malamocco and Chioggia, each protected by two jetties running seaward at about right angles to the shore. The Lido and Malamocco mouths, from 11 to 12 metres deep, at present constitute the entrances to the port of Venice.

The tide, which at Venice has a range up to a maximum of about 2 metres, exceeding by far the range of tide at any other part of the Italian coast, largely contributes, by its flow and ebb currents, to the maintenance of the salubrity and existence of both the lagoon and the city.

At present, the port of Venice consists of two distinct parts: the old portion, called the Maritime Station, on the eastern borders of the city, and the other, known as Port Marghera, constructed during recent years along the margin of the Lagoon, on the mainland; the latter is much more extensive than the Maritime Station.

Fig. 15.



VENICE (PORT MARGHERA): SECTION AT CC ON INDUSTRIAL CANAL.

The basins of the Maritime Station, having a total water-area of about 50 hectares bounded by the east and west moles, and the quays along the Giudecca canal, afford 4,436 metres of berths, of which 3,940 metres have depths of from 8 to 11 metres. They are provided with about 50 hectares of land and are equipped with sixty-three cranes having a total lifting-power of 209 tons. The quay-walls are of different types, in accordance with the different depths, soils and periods of construction. Some of the oldest walls are of concrete deposited within cofferdams, others are of the artificial-block type, or are founded under compressed air, while the most recent

ones, in depths of from 10 to 11 metres, are founded on reinforced-concrete caissons.

It was at the beginning of this century that, having regard to the rapid increase in the traffic, it was decided to take into consideration the problem of radically extending the port, in order to ensure its efficiency for a considerable time. After many years of investigations and discussions, I succeeded in obtaining the adoption of a layout planned by myself, and intended for the creation of a new commercial and industrial port on the margin of the Lagoon, as the only means of securing to Venice a suitable extension of the commercial harbour, an area large enough to accommodate any number of industries—thus contributing to the necessary revival of the economic life of the city—and a new town quarter, urgently needed for the demographic expansion of the city; all this could be obtained without causing any harm either to the Lagoon or to the natural beauty and monumental character of the "Queen of the Adriatic."

The design of Port Marghera covers a total area of about 2,000 hectares of swamp and lowland, having a front of 5 kilometres with an average width of 4 kilometres. In the scheme, the new commercial port covers—pending further extensions—a strip towards the Lagoon 1,500 metres wide, affording room for the construction of eight large jetties 1,000 metres long and 220 metres wide; this provides no less than 18 kilometres of berth frontage, available for a yearly traffic of from 12 to 15 million tons of merchandise. The first group of works, now nearing completion, concerns a commercial basin specially intended for the import of coal, with a depth of 9 metres (capable of being increased to 10 metres), bordered by 1,630 metres of quays, and amply provided with railway sidings and modern mechanical equipment, so as to deal with a yearly traffic of 1,500,000 tons. The quay-walls constructed up to now at Port Marghera are either of the well-foundation type or of the artificial-block type.

The access to Port Marghera from the Maritime Station is obtained through the Victor Emmanuel III canal, 4 kilometres long and 10 metres deep, with a bottom width of 90 metres, ending in a swinging basin to which all the other basins and canals of the new port converge. The new port is also connected, by a canal 3 metres deep for inland navigation, with the Brenta canal, which joins the Lagoon of Venice with Padua. At two-thirds of the way down the Victor Emmanuel canal there is the petroleum harbour, consisting of two basins and a reclaimed area of 40 hectares, occupied by several plants and factories for the storing, cracking, and refining of mineral oils.

The industrial zone, which, up to now, has been extended to a

reclaimed area of about 1,200 hectares, is provided, besides the necessary roads and railway sidings, with a vast network of ship-canals, generally 100 metres wide and 9 metres deep, which at present have a total length of 8 kilometres with 14 kilometres of berth-frontage, along which about forty factories have already been built. In all, there are at present in the industrial port seventy-four plants and factories of different kinds in operation, varying in importance and size and covering a total area of 3,400,000 square metres. These give work to eight hundred administrative staff and six thousand five hundred workmen.

Finally, an area of 150 hectares, adjoining the industrial port and suitable for further extension, has been reserved for a new building quarter, which, laid out as a garden city, will afford healthy and comfortable accommodation for about thirty thousand inhabitants.

(14) *The Port of Trieste* (Figs. 16, Plate 4) has a water-frontage of over 10 kilometres divided into two parts by the Sant' Andrea Point, and consists of three main basins and of a number of landing-places and wharves reserved for special traffic or private industries.

The three basins are: the Victor Emmanuel III Basin, of about 19·5 hectares water-area, with the adjoining Customs Basin, of about the same size, both situated in front of the city, and the Duke of Aosta Basin, with a surface of 13 hectares, south of the Sant' Andrea Point, at the entrance to Muggia Bay. Beyond the latter basin, after a coast section covered by shipyards, there is a timber wharf, followed by a steelworks wharf intended for the berthing of ships transporting iron-ore and coal, and by the San Sabba Basin for traffic in inflammable liquids.

The total water-area of the various basins is of about 86 hectares, the available land covers an area of about 28·5 hectares, and the total length of quays and wharves available for commercial purposes is 12,052 metres, of which total 3,758 metres are provided with quay-walls in deep water. The mechanical equipment of the port consists of one hundred and thirty-nine cranes, having a total lifting-power of 290 tons, and the warehouses cover a total area of 350,000 square metres. A large maritime station for overseas passenger traffic, covering an area of 43,120 square metres, has been constructed in the last few years. The whole of the commercial movement reached, in 1929, a maximum of one million, two hundred and ten thousand passengers and 2,860,000 tons of goods.

The protective works of the port, which is exposed to only moderate seas from the south-west and north-west, are a breakwater of the sloped type, 1,090 metres long, sheltering the Victor Emmanuel III Basin, and three breakwaters of the mixed type, with a vertical

wall of ordinary artificial blocks, sheltering the Duke of Aosta Basin and having a total length of 1,600 metres. The quay-walls are all of the artificial-block type, founded on a rubble mound, which is very high at some points, owing to the muddy nature of the bottom, or to the great depth of water, which in some cases is nearly 30 metres.

Characteristic Features of Fundamental Port-Works.

It is assumed that the term "fundamental port-works" refers to the quay-walls and the outer protective works. As for the quay-walls, the prevailing type still employed in Italy is the traditional pattern of contiguous piers of artificial blocks of pozzuolanic concrete, generally founded on a rubble mound.

With the exception of the modifications successively introduced in the profile and size of the quay-walls, in accordance with the varied forms and increased dimensions of ships, the only progress realized in the application of such types of wall consists in the using of blocks of greater and greater size, with the object of reducing both the time and the cost of construction. Such progress has been made possible by the construction of more powerful floating lifting-apparatus, in order to fulfil the growing requirements of the building of breakwaters of the vertical type.

In the more recent quays, constructed, for instance, at Genoa, and in those now in course of construction at the new port of Bari, which are founded at a depth of 11·50 metres and 10·50 metres respectively (Figs. 1, Plate 1, and Figs. 10, Plate 3), the quay-walls are composed of only three layers of artificial blocks, weighing up to 210 tons and 230 tons each. In the case of Bari, the two upper layers are made of the same cyclopean blocks used in the construction of the main outer breakwater, each divided into two parts.

In a few cases, where new quays were to be built in the immediate vicinity of other existing structures, like those required for the construction of the new maritime stations at Genoa and Naples (Figs. 1, Plate 1, and Figs. 3, Plate 3), the new quay-walls have been built in compressed air. In other cases, where new basins have had to be excavated inside the coast-line in loose ground very little above sea-level, the quay-walls have been constructed before the opening of the basin, the well type of foundation being used. This is the case with the south quay of the first commercial basin of Port Marghera at Venice (*Figs. 14*), and of the quay-walls at the new port of Leghorn (Figs. 2, Plate 2), with the exception that at Port Marghera it has been necessary, owing to the great permeability of the ground, to sink the walls partly by the aid of compressed

air. Again, in a few cases where sites for block-yards were defective, the quay-walls have been built of reinforced-concrete caissons, filled with pozzuolanic concrete. That is the case of several quays at the ports of Genoa, Naples, Cagliari and Venice (Maritime Station).

As for the quay-walls in shallow depths not exceeding 6 or 7 metres, the traditional type of mass concrete deposited within cofferdams has, in some instances, such as at Port Marghera and at the new port of Leghorn, been replaced by reinforced-concrete sheet-piles of the Coignet-Ravier system.

Finally, there are in Italy a great number of piers and wharves founded on reinforced-concrete piles, sometimes grouped together, as in the case of several wharves at Port Marghera (*Fig. 15*), into a reinforced-concrete cylinder filled with pozzuolanic concrete, in order to protect the piles both against shocks and also from the chemical action of sea-water.

But it is in the field of protective outer works that the most important evolution has taken place during the last 30 years in Italy, passing from the old sloped type of rubble mound, sometimes revetted by artificial blocks, to the vertical or mixed type.

The origin of the construction, in Italy, of the mixed type of protective outer work may be traced back for 40 years. At that time I had the opportunity, while on a scientific mission in the United Kingdom, to visit a great number of British ports, and I gave particular attention to breakwaters of the vertical or mixed type, chiefly at the ports of Dover, Sunderland, Tynemouth, Aberdeen, Peterhead, and Wick.

As a matter of fact, it was in studying such works that I became convinced that, by employing suitable systems of construction, the advantages of the vertical-wall type of breakwater could be realized in the tideless waters of the Mediterranean Sea, as well as on British shores where the large range of tide allows a fair portion of the work to be built in the dry at low tide. In the vertical-wall type of breakwater, the waves are reflected towards the offing instead of dissipating the full amount of their energy on the wall. I am, therefore, greatly indebted to Britain for the knowledge thus acquired, which enabled me to propose for the first time, in 1896, the application of the vertical type of breakwater to Italian harbour-works.

Four years later, when resident engineer at Naples, I had the opportunity of planning the first application of the new type of outer work for the construction of the outer wall (*Antemurale*) (Figs. 3, Plate 3), which was soon afterwards followed by several other applications, chiefly at the ports of Castellammare di Stabia, Salerno, Villa San Giovanni, Trapani, Savona and Cagliari.

All such cases were examples of works which were only moderately exposed, and for which it had been possible to construct the vertical wall from a solid mass of trimmed artificial blocks of ordinary shapes and dimensions, which were set by divers. There were already, however, thoughts of extending the application of the new type to more important and much more exposed works, and using structures consisting of much larger and heavier units. I pointed out, however, in 1905 at the 10th International Navigation Congress at Milan, that the systems of large monoliths generally used up to that time in the construction of a certain number of works of the mixed type abroad, such as those at Bizerta and Zeebrugge and at several Russian ports on the Black Sea, did not sufficiently fulfil the fundamental principles followed in Italy; this has been fully confirmed by experience. At the works mentioned, the wall had been constructed of huge monoliths formed of metallic or reinforced-concrete caissons filled in with concrete. I maintained at the time that such systems required to a large extent to be perfected, with a view mainly to reducing the difficulties of constructing and setting the monoliths, both in order to give the latter a more homogeneous structure in which there would be no material liable to deteriorate in salt water, and also to avoid the dangers that could easily arise from the sudden load of such enormous monoliths on a high rubble mound, even if built in accordance with the best principles.

The drawbacks so foretold were not long in being confirmed by the accidents that occurred shortly afterwards to several of these structures; accidents that should be ascribed either to building defects or defective profile and constitution of the rubble base, or to insufficient depth adopted for the foot of the wall, or, again, to excessive length of the monoliths.

Since then, constructive units have been sought which, whilst attaining the requisite degree of homogeneity in their structure, would enable those drawbacks which were inherent in huge monoliths, and which experience had confirmed in so striking a manner, to be avoided.

While pursuing the research in this direction a few years later, it was proposed, for large breakwaters in deep water which were exposed to rough seas, to build a structure of adjoining and independent piers, 5 or 6 metres long in the longitudinal direction of the work, each formed by the superimposing of a certain number of cellular blocks of a length equal to the thickness of the wall. These blocks were to be provided with large inner hollows, in order both to increase the apparent volume of the blocks as compared with their weight, and also to afford the means of joining together the blocks of each pier into a single monolith, by filling with concrete the wells resulting

from the superimposing of the hollows. The horizontal joints between the blocks were to be fitted with suitable packing, either of lead or of vegetable fibre, in order both to ensure the better bedding of each block on to the lower one and also to make the joints watertight; this was for the double purpose of getting a better result from the grouting of concrete into the wells, and of reducing to a minimum, if not wholly eliminating, upward dynamic pressures.

This system, first tested in an incomplete form in the construction of the Granili breakwater (Figs. 3, Plate 3) at the port of Naples, was fully adopted a few years later at the port of Genoa in the construction of a section of the breakwater sheltering the Victor Emmanuel III Basin, and also in the lengthening of the Galliera mole, by making the vertical wall (Figs. 1, Plate 1) of blocks of the apparent volume of 260 cubic metres and of an individual weight of 220 tons.

This first complete application of the new type of structure, while giving results that appeared, from the point of view of stability, to be entirely satisfactory, was not long in showing some drawbacks. These all resulted from the dimensions of the internal wells being too great, which weakened the blocks too much and exposed them, if an unexpected storm occurred before the wells were filled, to serious risk of damage. In addition, it had been noticed that the pouring of concrete into such vast hollows did not give sufficiently satisfactory results.

The ascertaining of these drawbacks, and the progress made meanwhile in the building of floating apparatus that could easily lift several hundreds of tons, led me to propose, towards the end of 1922, that cyclopean blocks should be substituted for the cellular blocks. The hollows were retained, but their dimensions were sufficiently reduced to eliminate all the above-mentioned drawbacks, while still permitting the connection of the units of each pier into a monolith. Furthermore, I formed the opinion that, in the case of works which were not unduly exposed, it might even be possible to avoid any hollow, using solid blocks of sufficient weight individually to give them the requisite resistance. These suggestions having been favourably received, the system of cellular blocks was abandoned, and was replaced by a structure of cyclopean blocks for the outer works either planned or in course of construction at Genoa, as well as for those successively planned for other ports, chiefly at Catania, Palermo, Bari, and Benghazi.

In the Prince Umberto mole at Genoa (Figs. 1, Plate 1), which is fully exposed to the prevailing storms coming from the south-southwest with waves which may exceed 6 metres in height, the vertical wall, having its foot at 11·5 metres below the mean sea-level, is of solid

cyclopean blocks, of an individual weight of from 300 to 350 tons. The wall has a thickness of 12 metres, increased at the base to 13·5 metres; its outer foot is protected by an apron of artificial blocks of dimensions 5 metres by 3 metres by $1\frac{1}{2}$ metre. The outer bench of the rubble foundation is 11 metres wide and its side slope is inclined at 1 in 2. Of the four blocks forming the piers, only the two upper ones are joined together by means of four small cavities, which were provided in the opposite faces of the two blocks and were filled with concrete after the blocks had been set.

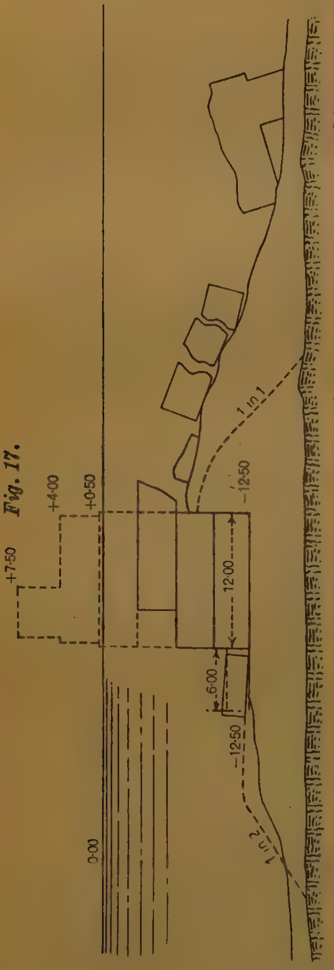
In the new arm of the San Vincenzo mole at Naples (Figs. 3, Plate 3), which is exposed to the prevailing south-westerly storms, with waves rarely exceeding 4 metres in height, the wall, 12 metres thick and founded at a level of —11·50 metres, consists of piers of three cyclopean blocks having an individual weight of 410 tons, which are joined into a monolith by filling with concrete two square wells with 1·80-metre sides; I still consider these wells to be of excessive size. The outer foot of the wall is protected in this case by a line of artificial blocks of dimensions 5 metres by 3 metres by 2 metres; the outer bench of the rubble foundation is 11 metres wide and its slope is inclined at 1 in 2.

In the new outer breakwater at Bari (Figs. 10, Plate 3), the second arm of which is fully exposed to the prevailing storms arising from east-north-east with waves of a maximum height of about 4 metres, the vertical wall, 10 metres thick and founded at a level of —10·30 metres, is made of cyclopean blocks, similar to those at Naples, having an individual weight of 320 tons. The outer toe of the wall is protected by an apron of artificial blocks of dimensions 4 metres by 3 metres by 2 metres; the bench of the rubble mound is 10 metres wide and its slope is inclined at 1 in 2.

In the new east mole of Catania (*Figs. 6, 7, 8* and *9*), exposed to violent storms coming from the east-south-east with waves which may exceed 7 metres in height, the wall, 12 metres thick and founded at the level of —12·50 metres, was to be constructed of four layers of cyclopean blocks weighing about 300 tons each, fitted with two hollows 2 metres by 1·25 metre to be filled with concrete in order to join the elements of each pier into a monolith. As in the case of the other similar works, the outer foot of the wall was to be protected by artificial guard-blocks, having dimensions of 6 metres by 3 metres by 2 metres, and the outer bench of the rubble mound was to have a width of 12 metres and a side slope inclined at 1 in 2. In carrying out the work, all these features were maintained, except that it was considered useless to make the piers in the form of a monolith; the hollow blocks were therefore replaced by solid blocks, and no packing for the horizontal joints of the piers was provided.

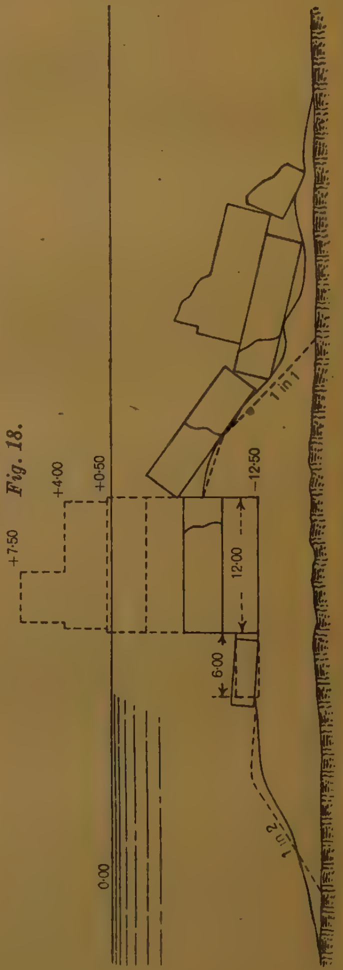
All the great breakwaters in Italy having a vertical wall of cyclopean blocks, with the sole exception of the new east mole of Catania, like those of lesser importance and having a wall of ordinary artificial blocks, have given satisfactory results up to the present

Fig. 17.



CATANIA: SECTION THROUGH PIER No. 103 OF NEW EAST MOLE AFTER STORM ON 26TH MARCH, 1933.

Fig. 18.



CATANIA: SECTION THROUGH PIER No. 73 OF NEW EAST MOLE AFTER STORM ON 26TH MARCH, 1933.

date. It has been ascertained, both at the Prince Umberto mole in the port of Genoa and at the new outer breakwater of Bari, as well as at the new east mole of Catania, that the depth adopted for the foot of the vertical wall, reduced by the existence of the guard-blocks to 10 metres in the first case and to 8·30 metres in the second,

was still not sufficient to ensure the necessary stability of the artificial guard-blocks and of the large quarry stones forming the bench and outer slope of the rubble foundation. The evil is now being removed in both cases by increasing to a certain extent the width of the bench and by making its side-slope flatter. At Catania, however, the construction of the new breakwater has unfortunately ended in disaster.

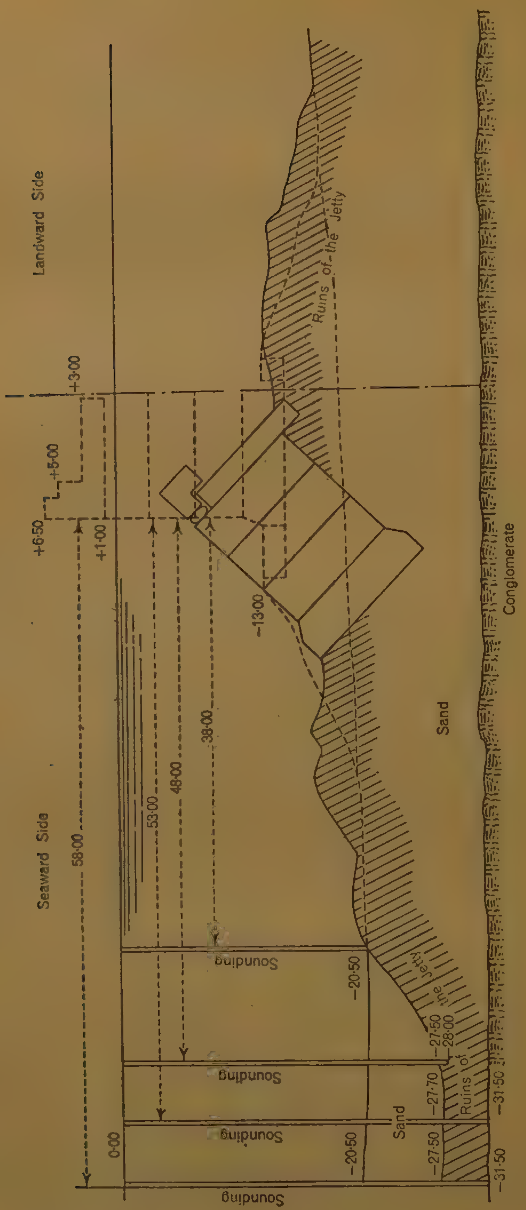
In February, 1930, during the onslaught of a storm of exceptional violence, which was characterized by a total absence of wind and by huge rollers about 7 metres high, the structure proved to be insufficiently strong. On a first section of the work, already provided with its superstructure, the wall was slightly displaced horizontally, whilst of the remaining length, all the blocks of the two upper layers, and also part of those forming the layer beneath, slipped inwards, some of them being even washed away. Only the blocks of the lowermost layer remained in place and were almost intact, whereas a very high percentage of the blocks forming the other layers were broken and split.

This damage was afterwards repaired, without any changes in the structure, except for the raising by 1 metre of the level platform on the harbour side, with a view to increasing the working load on the piers; the first arm of the jetty had been completely built up on its full length, when a further storm, which occurred on the 26th March, 1933, and which was still more severe than that of February, 1930, and was characterized by waves having the exceptional size of about 7·50 metres in height and 230 metres in length in the open sea, struck the breakwater and demolished it (*Figs. 17* and *18*).

With the exception of a section of the work at the start of the lengthening, about 100 metres long and buttressed inside by a large embankment, all the blocks of the two upper layers of the wall, and part of those of the layer below had, as in February, 1930, slipped on the top of one another towards the harbour side, tumbling over, with the superstructure, into a heap of ruins. The rubble foundation, but slightly damaged superficially, had, on the contrary, remained intact beneath the wall.

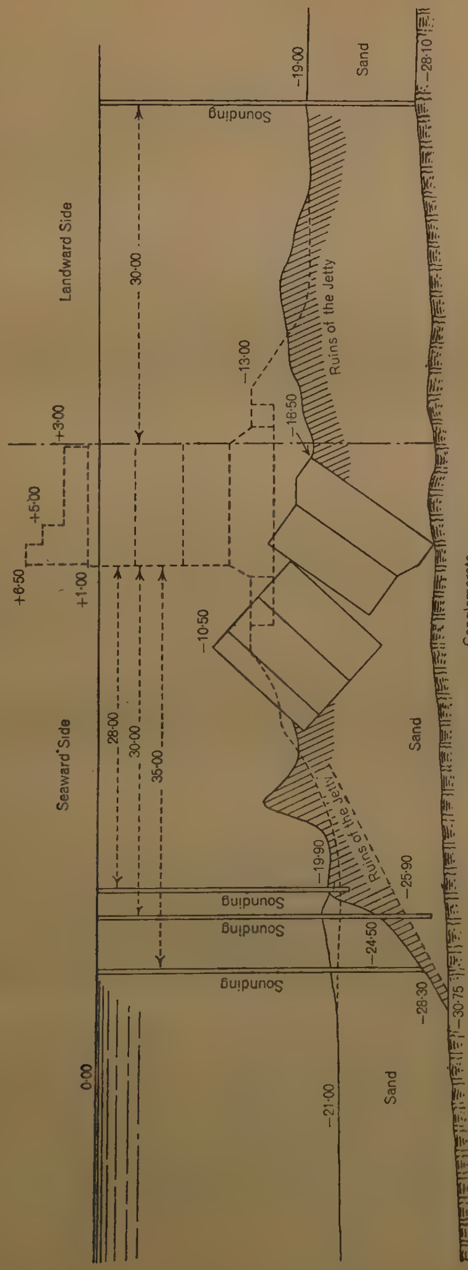
As a result of such a disaster, many people, in Italy and abroad, thought that the new type of work ought to be abandoned for breakwaters to be built in very exposed sites. Their conviction became firmer still, when, under the shock of a most exceptional storm which occurred in February, 1934, at Algiers, and characterized by a total absence of wind and by enormous waves 9 metres high and 300 metres long in the open sea, the last 400 metres of the second arm of the Mustapha jetty suddenly collapsed (*Figs. 19* and *20*, pp. 492–3).

Fig. 19.



ALGIERS: SECTION AT 1,180 METRES OF MUSTAPHA JETTY AFTER STORM ON 3RD FEBRUARY, 1934.

Fig. 20.



ALGIERS: SECTION AT 1,000 METRES OF MUSTAPHA JETTY AFTER STORM ON 3RD FEBRUARY, 1934.

I, on the contrary, had expressed the opinion since February, 1930, that the inadequate stability proved by the new mole at Catania ought to be ascribed essentially to the fact that the piers of that wall had not been made monolithic. I expressed the same opinion after the disaster of 26th March, 1933, and when the collapse of the Mustapha jetty took place, I saw in this new disaster the proof of the correctness of my opinion; the wall of that work, only 11 metres thick but formed by cyclopean blocks joined into monolithic piers, and founded on the rubble mound at a greater depth, had been able to withstand for many hours, without giving any signs of weakness, the formidable assaults of waves much larger than those of the Catania storm. It had only collapsed and overturned outside —contrary to what had happened at Catania—when the foundation-mound suddenly sank, and slipped into a large trench that the waves had scoured out at its foot, in a bottom constituted of a fine sand with no cohesion.

Thus, the analyses of both disasters led me to conclude that, far from justifying any doubt on the soundness of the type, these thoroughly confirmed it, for it followed logically from these analyses that, if in the case of the Mustapha jetty, the foundation-mound, owing to its structure and to the nature of the sea bottom, had been able to withstand the storm like that of the Catania mole, and if the structure of the wall of the latter had had the same monolithic structure as that of the Algiers breakwater, neither of the disasters would have happened; further, both the works might have come out of their formidable trials greatly exceeding all expectations, if not whole, certainly with much less serious and not irreparable damage. Both the works are, however, now being rebuilt on their ruins, in the old sloped type.

As stated above, all the works of the mixed type constructed in Italy, with the sole exception of the Catania mole, have given satisfactory results up to the present time. All these works had been planned on the basis of experience which was still, in Italy as in other countries, quite recent, and which still presented many uncertainties.

In Italy, the fundamental rules to be followed in building both the rubble mound and the wall were perfectly clear, but no experience had yet been acquired as to the requisite depth for the foot of the vertical wall, or as to the profile to be adopted for the foundation-mound. In the same way, nothing was known either of the intensity or the distribution of the efforts that the largest storm-waves would exert against the works, and on the sea-bottom at their foot.

It was in view of these uncertainties, and in conformity with a

resolution adopted by the XIVth International Congress at Cairo, that a special committee, in which Great Britain is represented by Sir Leopold Savile, K.C.B., M. Inst. C.E., was appointed with the object of undertaking or continuing systematic research on the pressures due both to oscillatory waves and to breaking waves.

According to this resolution, observations have been going on for over 4 years at Genoa by means of special appliances installed on the Prince Umberto mole, allowing the measurement and recording, at the same time, of the characteristics of waves and of the stresses they exert against the vertical wall at different levels.

The results obtained from the observations which have been so far recorded at Genoa, during storms which are characterized by waves striking the structure at right angles, although not attaining the expected maximum length nor exceeding 5 metres in height, are very significant.

They show clearly :—

(1) That horizontal stresses (that is, excess of positive or negative pressure, according as it is either landwards or seawards, compared with the calm-water conditions) exerted by oscillating waves reach a positive maximum value, generally a little below the level of a smooth sea.

(2) That the maximum effort is very nearly equal in all cases to the hydrostatic pressure due to the height of the waves impinging against the wall.

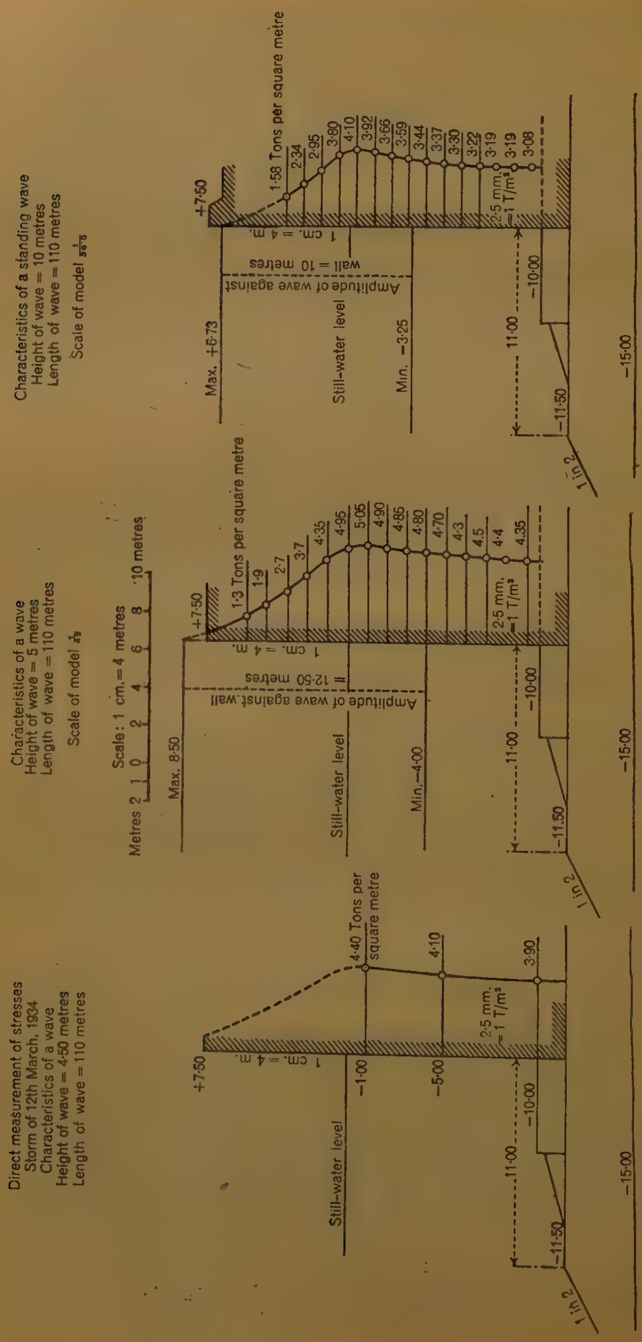
(3) That this same effort diminishes rapidly above the smooth-sea level, notwithstanding the fact that the breakwater-parapet may be surmounted by waves the crests of which on frequent occasions surpass the theoretical heights corresponding to an amplitude of oscillation double the height of the incident waves: this fact alone proves, at the outset, that the pressures exerted by waves against walls are not of a simple static nature, but are a combination of static pressure and dynamic effort.

(4) That the positive maximum effort diminishes, on the other hand, below smooth-sea level, all the more slowly as the ratio of height to length of the wave becomes less. In the case of waves of ordinary proportions, the effort is reduced at the foot of the wall to a value which always exceeds one-half the maximum, while it remains sensibly uniform and equal to the maximum in the case of waves which are exceptionally long as compared with their height.

(5) That the negative effort below the trough of the wave in contact with the wall is sensibly equal, at all levels, to the corresponding positive effort.

In order to check and complete these results as far as possible, in accordance with the resolution of the Cairo Congress, and with the

Figs. 21.



Note. The vertical wall of the model does not permit any overflow

WAVE-ACTION AGAINST VERTICAL BREAKWATERS: TESTS WITH SMALL-SCALE MODEL OF PRINCE UMBERTO MOLE, GENOA.

view in mind at the same time of analysing more closely the circumstances attending the disasters at Catania and Algiers, I undertook some months ago, in collaboration with Mr. A. Stucky, Professor of Engineering and Director of the Hydraulic Laboratory at the University of Lausanne, a series of tests on small-scale models. The results of these tests, although they are still incomplete, appear to me to be very significant.

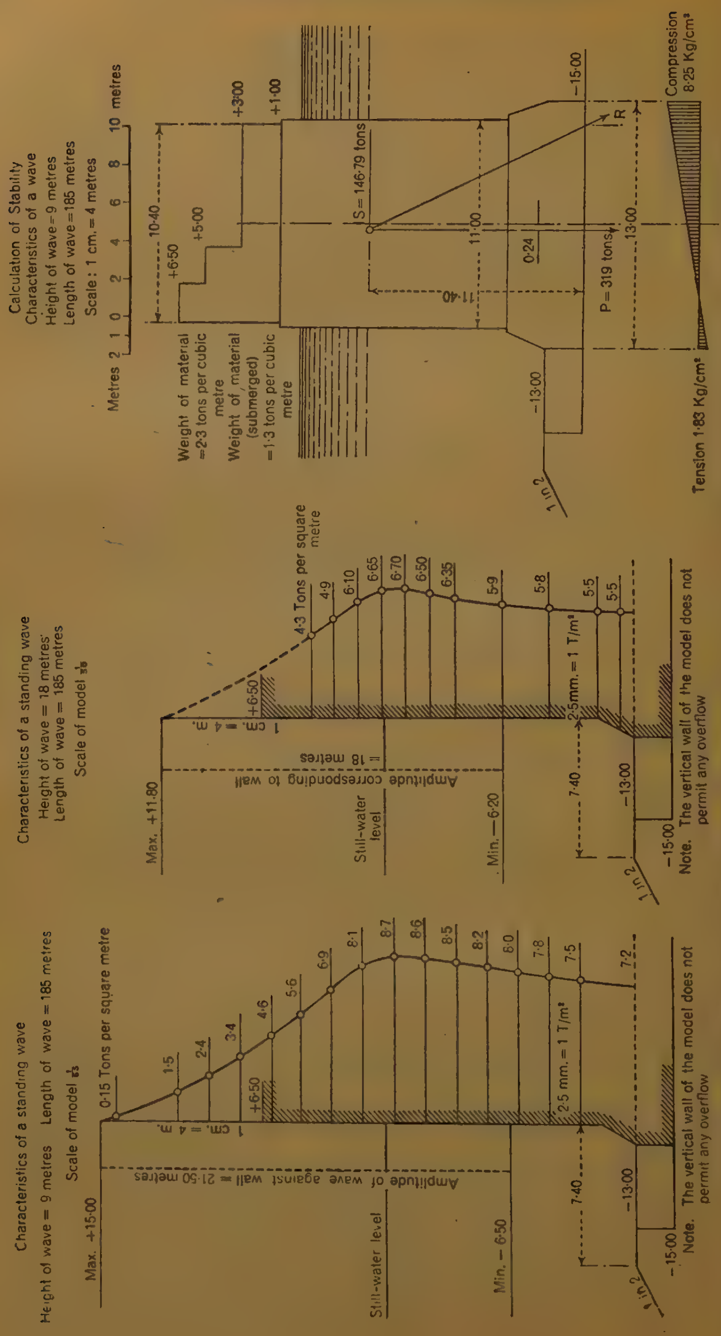
These results may be summarized as follows :—

(1) The perfect agreement between the actual observations recorded at Genoa and the results of the corresponding tests on the model of the Prince Umberto mole shows, on the one hand, that the method of research by means of tests on small-scale models, based on the law of mechanical similitude, is strictly applicable to the study of wave-effort. On the other hand, in opposition to the opinion held by some authorities, the results show that oscillating waves, at any rate in violent storms, are not converted by reason of their reflection at a vertical wall into actual "standing waves," but rather that they maintain their essential characteristics as trochoidal waves with orbital, though modified, movement, and also that they exert pressures that considerably exceed those which would be produced by an actual standing wave engendered by the same trochoidal wave. This is clearly shown by the diagrams in *Figs. 21*, from which it will be seen that the total effort exerted, in the case of the mole at Genoa, by an ordinary wave 5 metres high and 110 metres long exceeds by 26 per cent. the total effort that would be exerted by a standing wave engendered by the same ordinary wave, and having therefore the same length but twice the height.

(2) The tests on a small-scale model of the Mustapha jetty at Algiers have shown (*Figs. 22*, p. 498) that, under the assault of the terrific storm of the 3rd February, 1934, with waves 9 metres high and 185 metres long in the immediate vicinity of the work, the wall experienced a total effort of 147 tons per linear metre of structure, greater by 35 per cent. than that which would be exerted by a standing wave of the same length and 18 metres high. As a consequence of this effort the intensity of pressure on the rubble mound at the inner edge of the base of the wall, should have amounted to 8·25 kilograms per square centimetre; certainly an excessive load, but one which, very likely, was not actually realized to the full extent of the calculation by reason of the intervention of other factors of resistance, such as the continuity of the mass-concrete crown of the breakwater and the rise of the water inside the sheltered area as a result of the rise in level outside.

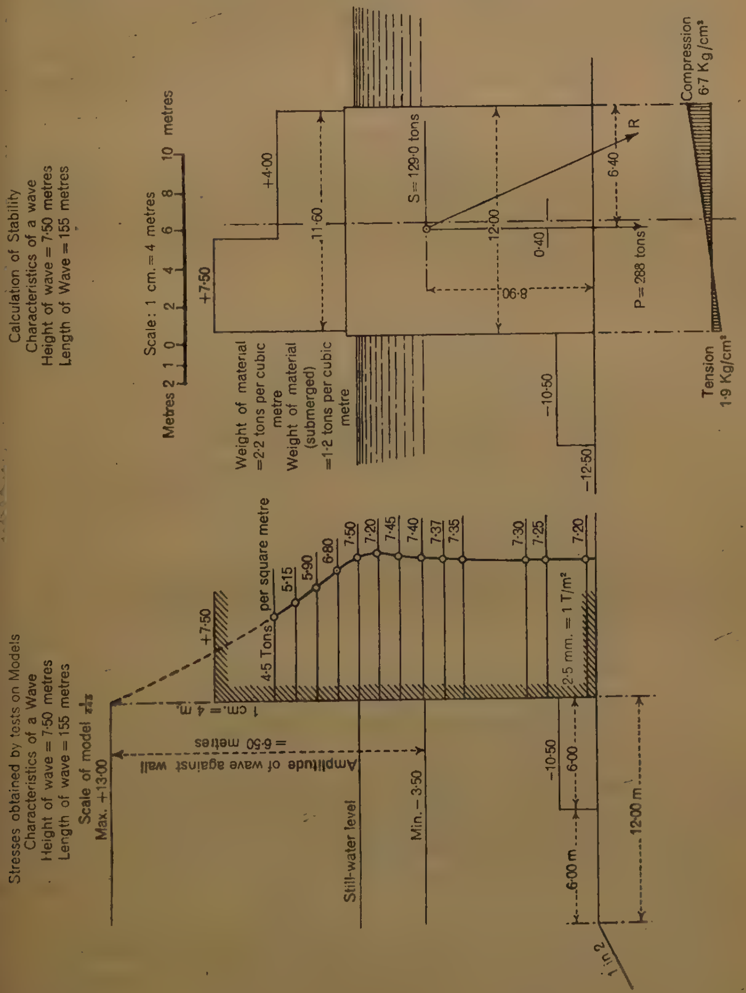
(3) The model of the Catania mole having, in turn, been subjected to the impact of waves 7·50 metres high and 155 metres long adjacent

Figs. 22.



WAVE-ACTION VERTICAL BREAKWATERS: TESTS WITH SMALL-SCALE MODEL OF MUSTAPHA JETTY, ALGIERS.

to the structure, similar to those observed during the storm of the 26th March, 1933, the results of the test showed (*Figs. 23*) that the wall experienced a total effort of 129 tons per linear metre of structure, producing an intensity of pressure on the rubble foundation of



Figs. 23.

WAVE-ACTION AGAINST VERTICAL BREAKWATERS: TESTS WITH SMALL-SCALE MODEL OF NEW EAST MOLE, CATANIA.

6·70 kilograms per square centimetre: a pressure which the wall, 12 metres thick, would clearly have withstood better than the Algiers jetty if it had, like the latter, been constructed of piers of cyclopean blocks formed with wells, which had been afterwards filled up with concrete. It can, however, be understood that the mass of the super-

structure with the block immediately beneath, having a total weight of about 150 tons per linear metre, although no doubt reduced by the pressure of the water on the under surface exerted through the unbedded horizontal joints, might have been displaced by a pressure of 60 tons, and that subsequently the blocks in the lower layers would have been in their turn, and still more easily, carried away.

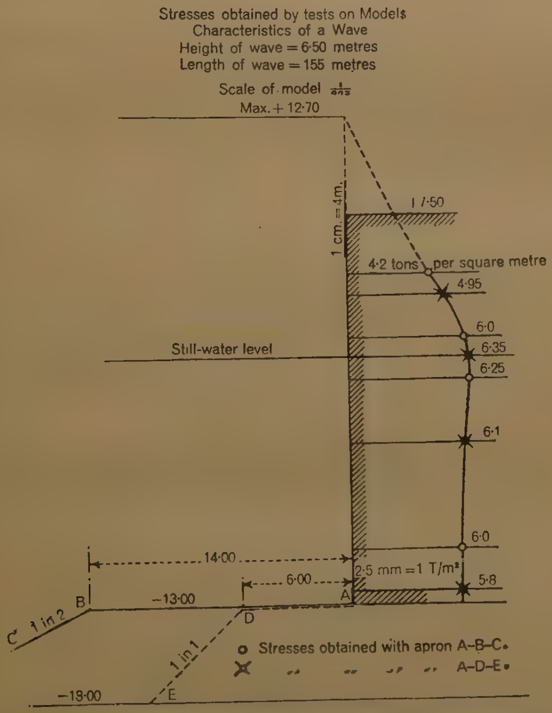
(4) The results of all the experiments on small-scale models have led to the conclusion that the intensity of effort in tons per square metre by oscillating waves against a vertical wall diminishes in the ratio of about two-thirds of the height above the smooth-sea level. Thus, with a surface-level pressure of, say, 6 tons per square metre, the pressure at a height of 3 metres above sea-level would be reduced by $3 \times 2/3 = 2$ tons per square metre, to a value of 4 tons per square metre.

In none of the three cases submitted to test with small-scale models, relating to breakwaters at Genoa, Algiers and Catania situated in depths of 15 metres, 21 metres and 18 metres respectively, and having the bases of the vertical walls located at depths of 10 metres, 13 metres and 10·50 metres, could waves of the maximum heights of 7 metres, 9 metres and 7·50 metres be caused to break, even superficially, in front of the wall, although given an increase of length in the open sea beyond any admissible proportion, up to about forty times their height. In all these cases, in fact, a maximum unitary effort was produced, almost exactly uniform over the whole immersed part of the wall and equal, as in all the other experiments, to the hydrostatic pressure due to the height of the waves. It is therefore justifiable to conclude that, if the depth of the sea at the site of the work exceeds, as is usually the case, twice the height of the greatest storm waves to be expected in the locality, and if the foot of the vertical wall lies at a depth of one and a half times the same height, there should be no danger of waves completely breaking against the work. Moreover, it has been possible to ascertain that, under these conditions, the width of the benching at the foot of the wall and the inclination of the side slope do not affect in any way the intensity of the stroke exerted by the waves against the wall (*Fig. 24*).

While, however, under the foregoing conditions, it is possible to exclude the risk of the heaviest storm-waves breaking completely against the work, it is not impossible that, during storms attended by very strong winds, the waves, retarded in their propagation by the progressive decrease in sea-depth and by the effect of the slope of the rubble foundation, may, under the influence of the wind, break superficially and so produce against a part of the face of the wall pressures which are much more intense than those which would be

exerted by the same waves if they remained purely oscillatory up to the point of contact with the wall. Unfortunately, no observation or experiment has so far provided any data as regards the intensity and distribution of these exceptional pressures, so that no precise indication is available of the degree of additional support which may be required to counteract such wave-strokes. However, it should

Fig. 24.



Wave-action against Vertical Breakwaters: Stresses obtained on Small-scale Model of New East Mole, Catania.

be noted that waves accompanied by strong wind are sensibly shorter than waves of the same height propagated in the complete absence of wind, with the result that the total effort exerted against the wall is considerably less in the first than in the second case; on the other hand, the effort which is exerted by the breaking wave, and which is purely dynamic, exhausts itself in a comparatively short time, and affects the resistance of the wall to shear much more than to overthrow or to slip. It follows, in my opinion, that, if the work

is designed with the requisite margin of safety for withstanding oscillating waves of the maximum height to be anticipated in the locality, unaccompanied by wind, the monolithic structure of the wall itself, or of its piers, may suffice to ensure the requisite stability against the increased stroke during storms accompanied by strong wind, which may arise from waves of maximum height which happen to break superficially on approaching the wall.

The results described above have so far been obtained, both from observations and from tests on small-scale models. They should not be considered as exhaustive, but in my opinion they may serve to substantiate the principles which I have previously enunciated on the subject of the construction of vertical breakwaters, as embodied in the following conclusions :—

(1) If the depth of water and the rocky nature of the sea-floor allow of its application, the best system of construction consists in founding the wall directly on the sea-bed, having previously levelled the site with material which is not subject to deterioration in a marine environment.

If, on the other hand, the excessive depth of water or the softness of the sea-floor require the formation of a rubble foundation, the latter should be constructed with the greatest possible degree of compactness. With this object in view, it is necessary to mix in bulk quarry stone of varying sizes (the largest being set as surfacing), in order to reduce the volume of the vacuities to a minimum. In addition to this it is advisable, in the case of mounds of considerable height, to deposit the material in successive layers and as long as possible in advance of the construction of the vertical wall, so that the rubble may have sufficient time to settle and solidify before receiving the weight of the wall.

(2) In principle, a vertical-wall breakwater should be avoided, or at any rate, that type of work must be considered disadvantageous, if the site is conducive to the complete breaking of storm-waves.

In the present state of experience and of theoretical and experimental knowledge, it appears that any danger of the complete breaking of storm-waves in front of a vertical-wall breakwater is excluded when the depth of water at the foot of the work is at least twice the height of the greatest storm-waves likely to be encountered in the locality, whatever be their length, within the limits of actual observation (that is, from thirty-five to forty times the height, at the utmost, in the greatest storm-waves so far observed).

(3) Within the limits of depth practicable with the present state of constructional technique, the foot of the vertical wall should be located deeper below sea-level for more exposed structures than for more sheltered ones, so that the largest waves anticipated may

retain their oscillatory nature while travelling over the slope and benching of the rubble mound, and so that the mound itself should not be exposed to disturbance from the motion of the sea.

In accordance with the lessons so far gained from experience, a depth of about 10 metres at the foot of the vertical wall which is directly exposed to wave-stroke may be considered as sufficient, if the anticipated height of the waves does not exceed 4 or 5 metres. In the case of more exposed works, the depth should be increased to 12 or 13 metres at least.

In all cases it is advisable, in order better to ensure the stability of the wall, to embed its base, suitably widened, within the rubble mound, rather than to protect its outer foot by a line of guard-blocks forming a projection on the rubble benching.

(4) The benching should be made wider (from 10 to 15 metres) and the outer slope of the rubble mound flatter (from 1 in 2 to 1 in 3), where the structure is more exposed and the sea-floor is more liable to disturbance, than for more sheltered conditions.

In the case of loose earth, easily erodible and at no great depth, the adoption of the vertical-wall type of breakwater might entail the necessity, eventually prohibitive from an economic point of view, of protecting the bottom over a considerable width in front of the outer foot of the work by suitable means, such as a layer of quarry stone laid either directly on the ground or on a mattress of fascine-work.

(5) Under the conditions stated in conclusion (3), the total maximum effort to which the wall may be exposed by the maximum wave-stroke likely in the locality can be calculated, on the basis of a unit pressure equal to the hydrostatic pressure due to the height of the wave in the open sea, applied uniformly throughout the whole extent of the wall below the smooth-sea level, and lessening progressively above that level at the rate of two-thirds of the height. In selecting the type of structure for the wall, however, account must also be taken of the supplementary shock which may possibly be exerted by waves of the maximum height if, while approaching the breakwater, they happen to break superficially by reason of wind-action.

(6) In the case of slightly or moderately exposed works, the wall may consist of a mass of bonded artificial blocks of ordinary shape and size. In the case of works much more exposed or exceptionally exposed, it is necessary to have recourse to units of much greater dimensions extending throughout the full thickness of the wall, such as cyclopean blocks superposed either in inclined layers, as is more particularly suitable for a wall founded directly on a rocky bottom, or in vertical piers, as is usually the case for walls founded

on a rubble mound, or else consisting of monolithic sections formed by caissons about 5 or 6 metres wide filled with concrete.

These monolithic sections undoubtedly represent the best solution from the standpoint of stability of the wall, and are all the more recommendable nowadays seeing that the cement industries are producing special aggregating materials which afford the surest guarantee of resistance to chemical action in sea-water, to an extent no less than that of ordinary mortar made with rich lime and pozzuolana.

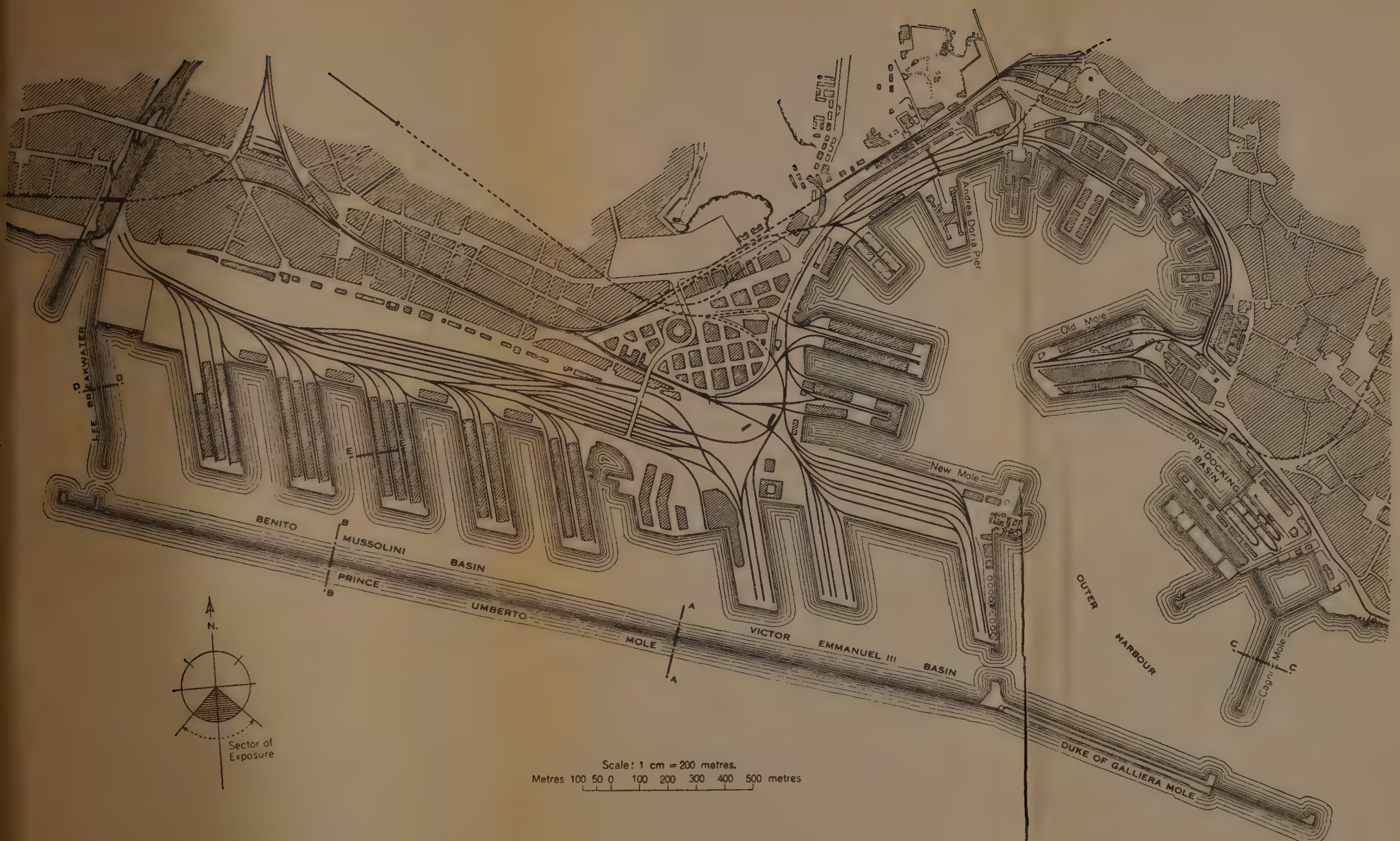
If, however, the local conditions are not of a nature to allow of the adoption of such a structure with advantage, an equivalent solution, besides being simpler and safer in application, consists in building the piers in cyclopean blocks, with wells or cavities, capable of being converted into a single monolith by filling the wells with concrete, preferably reinforced with steel bars.

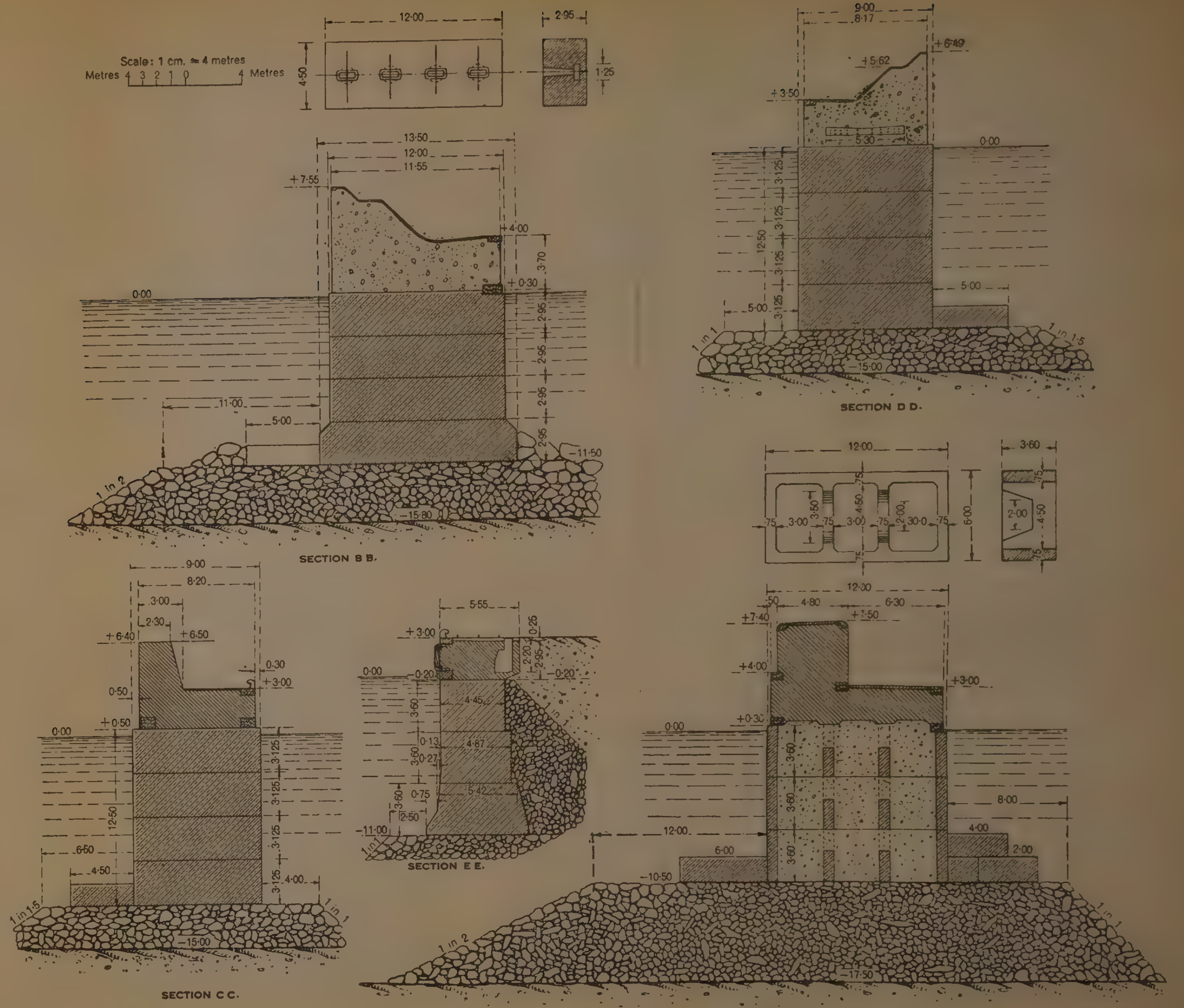
The monolithic structure of such piers, obtained by one or other of the methods suggested, has the advantage not only of augmenting the resistance of the wall to overturning without increasing its width, but also of enabling it to withstand any additional force or impact exerted by the heavier storm-waves should they happen, by reason of wind-action, to break superficially in front of the breakwater.

In any case, whatever the structure of the piers, it is necessary to unite them by means of the superstructure (after allowing the piers to settle *pari passu* with the rubble base, especially in the case of a high mound-foundation), with the object of making the whole wall, when its construction is completed, and further and unequal settlement is no longer to be feared, a solid monolith with suitable filling of the joints between the vertical piers.

ITALIAN DOCKS AND HARBOURS.

FIGS: 1.





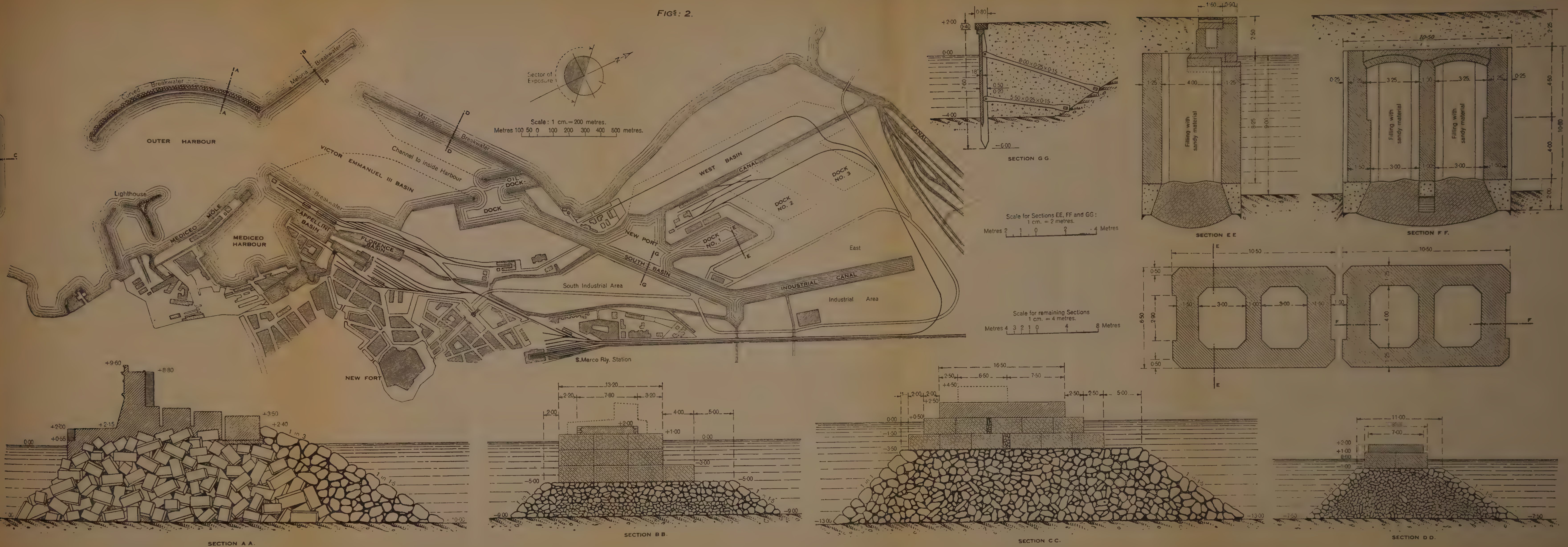
GENOA.

H. C. CAGLI.

Waterlow & Sons Limited, late Thos. Kell & Son, London

ITALIAN DOCKS AND HARBOURS.

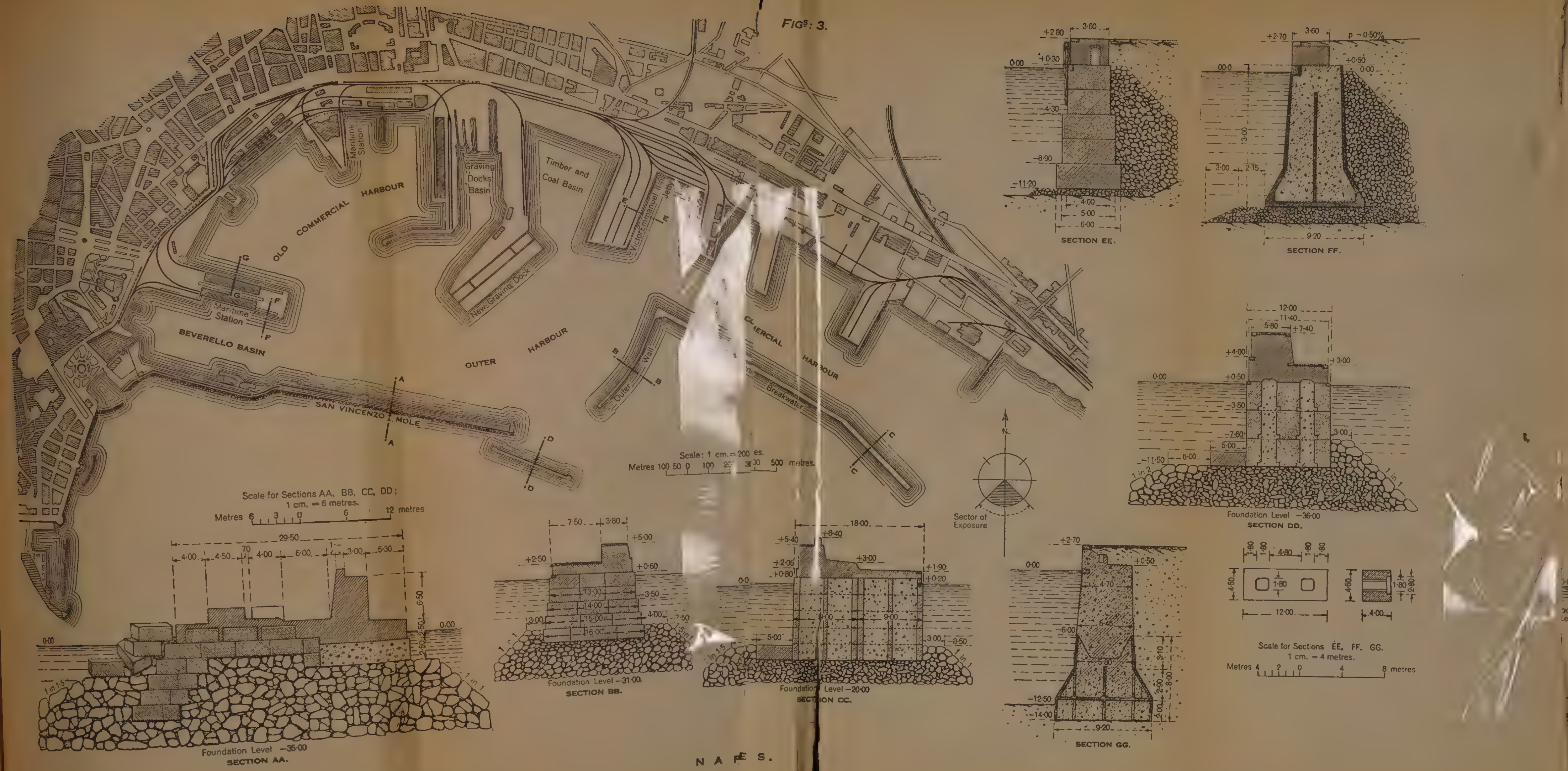
FIGS: 2.



LEGHORN.

H. C. CAGLI.

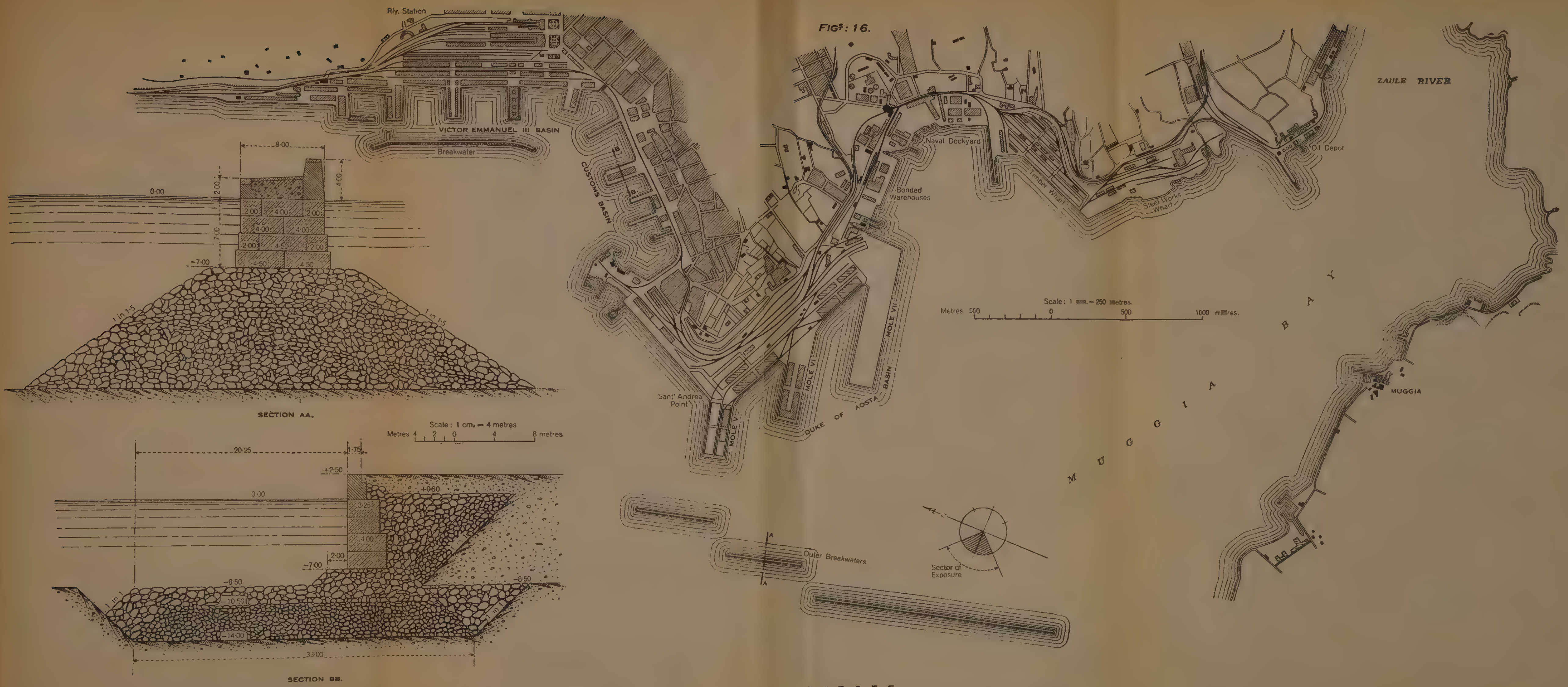
ITALIAN DOCKS AND HARBOURS.



H. C. CAGLI

ITALIAN DOCKS AND HARBOURS.

FIGS: 16.



TRIESTE.

H. C. CAGLI.

WATERLOW & SONS LIMITED, LATE THOS. KELL & SON, LONDON.

(Paper No. 5029.)

"Reinforced-Concrete Chimney Towers at the Barton Power-Station."

By Arnold Atherton, B.Sc.

(*Ordered by the Council to be published without oral discussion.*)

TABLE OF CONTENTS.

Introduction.

When the Barton Power-Station of the Manchester Corporation Electricity Department was opened in 1923, the station was equipped with four boilers, each with its own steel chimney, 9 feet in diameter, which discharged at a height of 121 feet above the ground, 31 feet above the level of the boiler-house roof. In August, 1924, five further boilers were added with similar chimneys.

Difficulties arising from the alleged harmful effects of smoke and fumes from the station led to the original chimneys being raised, between 1924 and 1926, in two stages of 20 feet each, to a height of 161 feet above ground-level. In 1930 the chimneys, which had suffered considerable internal corrosion, were replaced by 7-foot diameter stacks, each 190 feet high, the reduction in diameter permitting greater height without over-stressing the supporting framing.

The first section of the station was completed in 1927, and No. 10 boiler was installed. Pulverized fuel was used for this boiler, and a 9-foot diameter steel chimney, 161 feet high, was provided, which, after being raised to 201 feet in 1930, was replaced by a chimney 8 feet in diameter in 1933. Boilers Nos. 11 and 12 were installed in 1928, each with a 9-foot diameter steel chimney 161 feet high. In 1930 these were extended to 230 feet in height, with a diameter

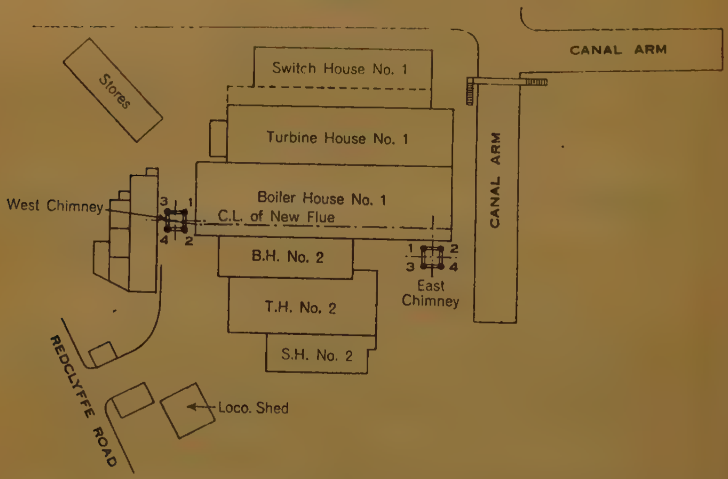
of 8 feet. Boiler No. 13, having a 300-foot self-supporting steel chimney, was installed in 1931.

These alterations to the original chimneys involved new guying systems, and the supporting steelwork under the chimneys had to be strengthened.

The maintenance costs of steel chimneys are considerable, and it was decided to replace them, at the completion of their economic life, with two large stacks 300 feet high and 18 feet 9 inches in diameter at the top, situated at the east and west ends of the station respectively.

It was intended to dismantle the existing steel chimneys down to

Fig. 1.



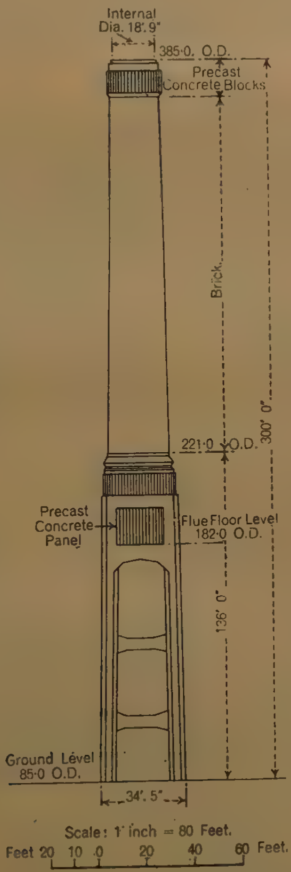
the level of the boiler-house roof, and then to transfer the flue-gases into a new main flue, situated on the existing boiler-house roof, above the coal conveyers and bunkers. This flue was to discharge high above the ground into two new brick chimneys, each 18 feet 9 inches in diameter, placed one at each end of the boiler-house (*Fig. 1*).

Owing to the proximity of existing buildings and the limitations of additional loadings on the original steel framework, little choice was possible in deciding the location of the chimneys. At the west end it was necessary for the tower to accommodate a railway-track and turntable directly below. Constant access for traffic to the turbine-room and workshops was also essential during construction.

Since the main flue would discharge into the chimneys at the level of the boiler-house roof, or at a height of about 100 feet above the

ground, it was only necessary for the chimneys proper to start at that level. It was decided that the lower portions should take the form of open braced reinforced-concrete structures, each consisting essentially of four octagonal columns, 120 feet in height, with four systems of horizontal bracings (*Fig. 2*).

Fig. 2.

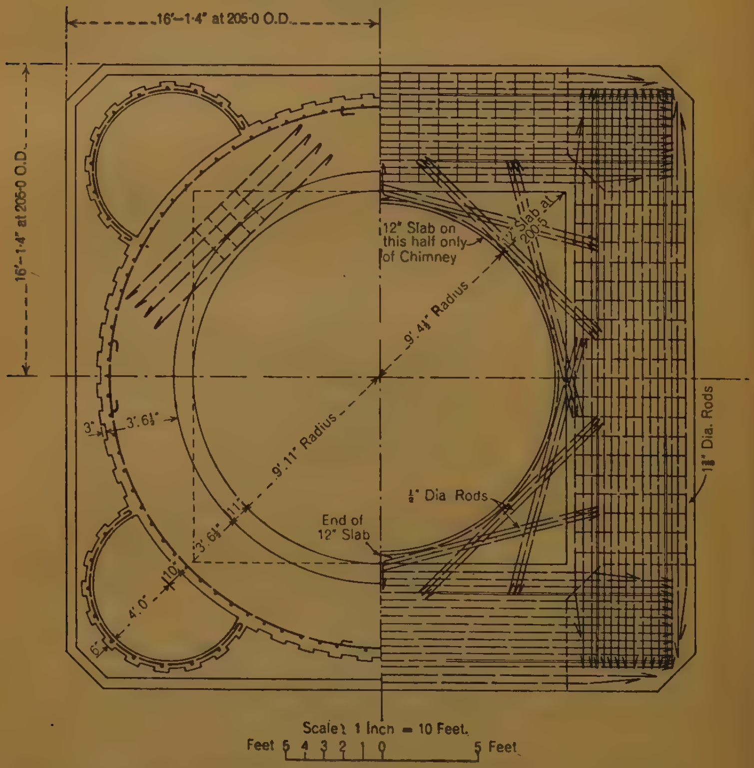


In the case of the east tower, the open braced type of design proved valuable in providing accommodation for a sump for the new water-borne ashing system; this was arranged below ground-level in the base of the tower, and the telpher runway for the grab which operates at the sump is also carried by the tower bracings. Above ground-level the two towers are identical.

In preliminary designs it was proposed that the brick stacks should

start directly off the top system of bracings; to overcome the sudden change from the square section of the concrete towers to the circular section of the brick chimneys, the base of the stacks were to be cased to a height of 16 feet with pre-cast concrete units, and circular fluted features each 10 feet 6 inches high were to be introduced over the legs of the column. Later, this decorative work was incorporated in a circular concrete base 16 feet high, monolithic with the top system of bracings (*Fig. 3*). For aesthetic reasons,

Fig. 3.



there is a fluted capping of precast concrete units at the tops of the chimneys. The panels between the top and second bracings which enclose the chamber where the flue joins the chimney are also carried out with pre-cast concrete units, with suitable reinforcement, giving a vertical fluted effect as shown in *Fig. 4*.

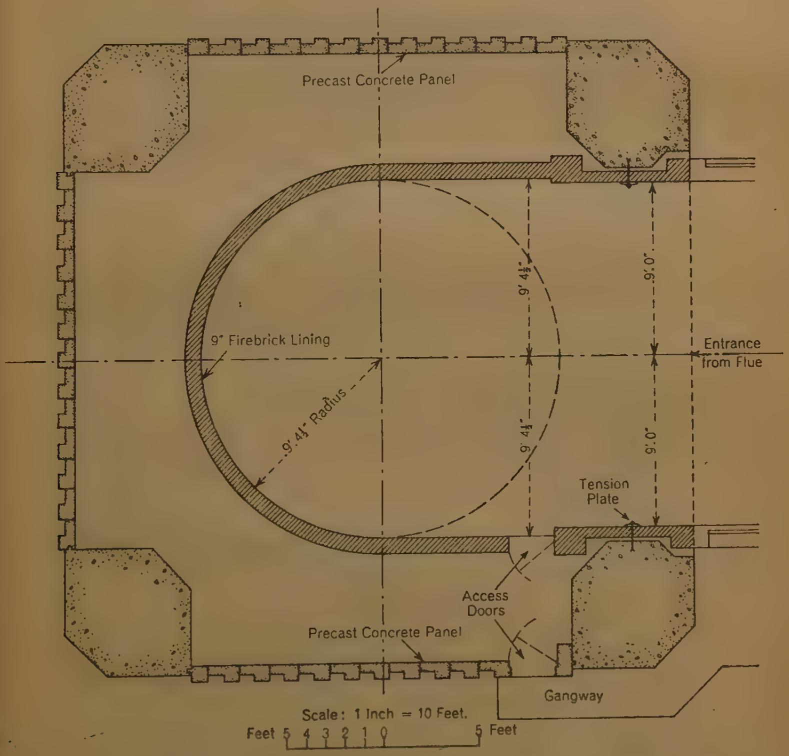
The total height of the concrete towers is 136 feet. The octagonal legs are 130 feet in height and are 6 feet 6 inches across the flats, and they are reinforced with forty-eight $1\frac{3}{8}$-inch diameter vertical bars

and with $\frac{1}{2}$-inch-diameter spiral hooping at 4-inch centres. The bracings are 5 feet deep at the centre and 2 feet $8\frac{3}{8}$ inches wide, with symmetrical reinforcement at the top and bottom, and are shown in detail in *Figs. 5* and *6* (pp. 510 and 511).

Design.

The principal difference between the designs of the two towers lies in the degree of fixity at the base. The columns of the west tower

Fig. 4.

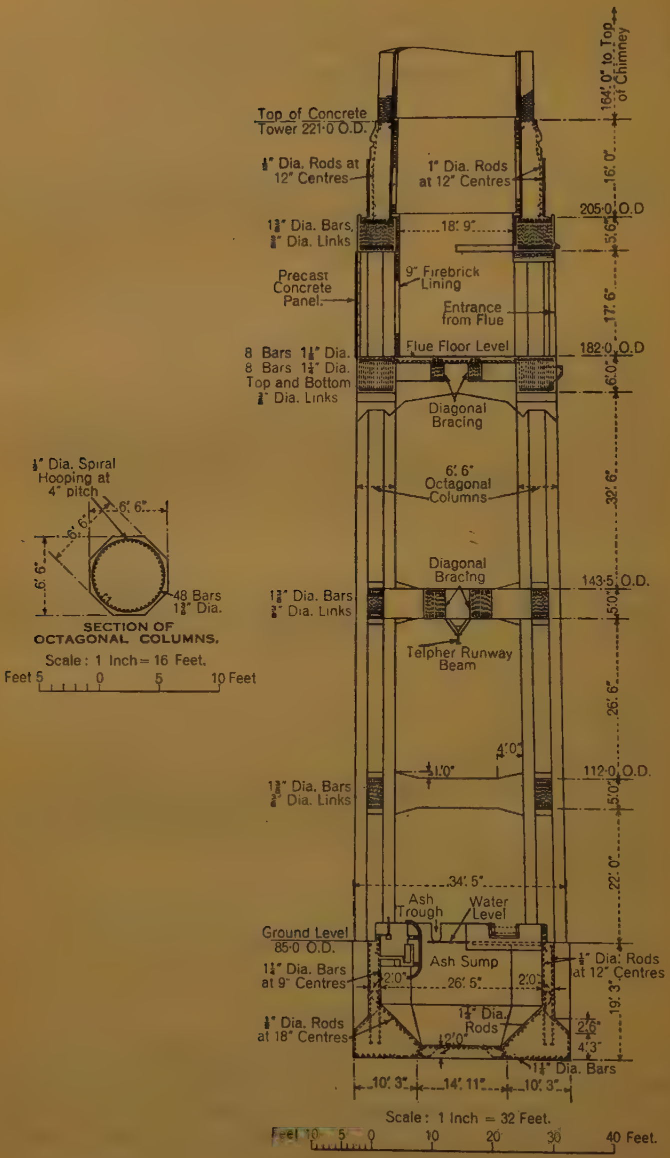


are carried on four independent bases, and although each is carried down 10 feet below the ground into solid rock, the degree of fixity is not so high as in the monolithic base of the east tower. To cover this variation, the towers were designed for the worst cases arising from fixed and free conditions at the base.

While the dead load of over 1,600 tons from the brick stacks on the towers is considerable, the primary factor which influenced the design was the wind-load. At some points in the columns over

33

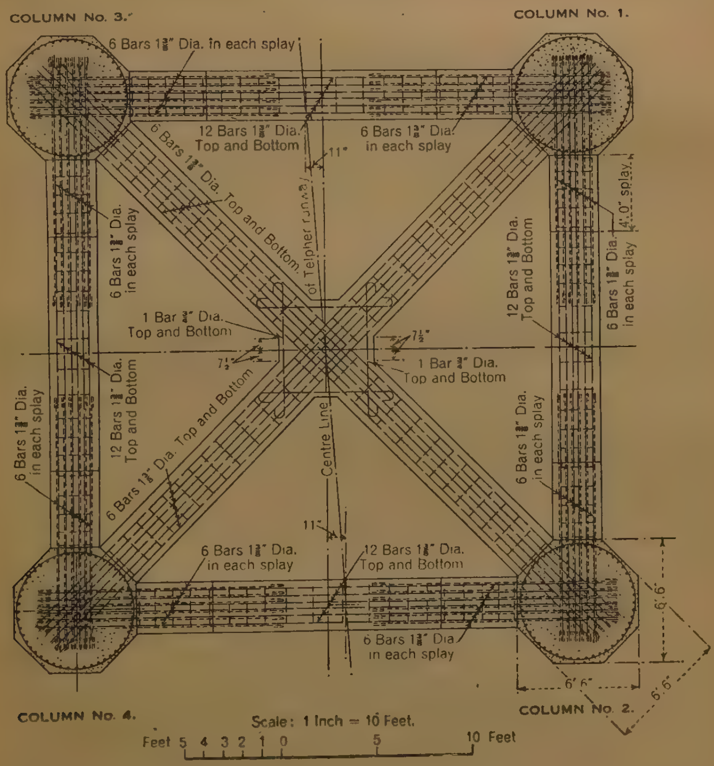
Figs. 5.



60 per cent. of the total stress is due to wind-load, and some of the more important points in the determination of the stresses will now be considered.

The analysis of statically indeterminate structures, particularly those encountered in tall buildings resisting wind-pressures, has received considerable attention recently, and in 1932 Professor Hardy Cross described [1] a new method of analysis for such frameworks. This method has been further developed by other authors, and a modified form of Professor Cross's method was adopted in

Fig. 6.



this case; this resulted in a considerable saving of time over that necessary in the old "slope-deflection" method.

Strictly speaking, the towers should be considered as three-dimensional rigid structures standing under wind-loads which can act from any quarter. If the small effect of torsion in the members is neglected, this analysis can be reduced to that of a two-dimensional

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[1] "Analysis of Continuous Frames by Distributing Fixed-End Moments," Trans. Am. Soc. C.E., vol. 96 (1932), p. 1; and discussion thereon.

rigid frame, made up of two of the legs of the column and their common cross bracings, by splitting up the wind-load into its components along the axes of the tower.

The two principal cases to be considered are therefore :

(1) Wind acting at 45 degrees to one of the axes ;

(2) Wind acting along one of the axes.

These cases provide maximum and minimum values for the bending moments and shears, and cover all intermediate directions of the wind.

A rather unusual point arose when determining the effective length of the bracings. The columns are 6 feet 6 inches across the flats, and the distance between the centres of the legs is 27 feet 6 inches. The question was whether the effective length of the bracing should be taken as the clear span of 21 feet, or as the distance between the centres of columns, which is 27 feet 6 inches. In all probability, the best value to take is one slightly greater than the clear span, on the assumption that some deformation takes place inside the columns. Actually, the clear span was used, and at the same time the effect of the haunching of the bracings was taken into account. The combination of these two refinements was rather surprising, and the modified stiffness of the bracings is very nearly doubled. As the moments taken by the bracings are proportional to their stiffness, these modifications, if neglected, will cause the stresses in the bracings to be under-estimated by nearly one half of their probable value.

The greatest stresses in the columns occur at the top and at the base, and are shown in the following Table :

Location.	Dead-load stress : pounds per square inch.	Wind-load stress : pounds per square inch.	Total stress : pounds per square inch.	Direction of wind.
Top	270	480	750	45 degrees to axes.
Base . . .	575	250	825	45 degrees to axes.

The bracings are designed for a maximum stress of 650 pounds per square inch in the concrete.

The stress of 825 pounds per square inch in the concrete at the base of the columns was considered safe in view of the nature of the spiral hooping, and is well within that allowed in the recommendations of the Reinforced-Concrete Structures Committee.

It was felt, however, that, due to the unusual nature of the structure, there would be some additional stresses due to shrinkage

and creep, and it was while attempting to evaluate these stresses that the desirability of taking some actual strain-measurements in the towers was realized.

Bricks of high crushing-strength were employed for the stacks, and it has been possible by their use to reduce the shell-thicknesses and resultant dead load on the towers to a minimum. The batter of the chimneys is so slight that facing-bricks of constant radius have been used throughout.

Materials.

Aggregates.—The whole of the natural and crushed-gravel aggregate and sand came from the contractor's own quarries near Agecroft, and were specially selected from the results of a number of tests on different aggregates, which were carried out to determine their acid-resisting properties. In the large reinforced-concrete members a maximum size of $1\frac{1}{2}$ inch was used for the aggregate.

The sand was found to possess considerable bulking properties, and a 5 per cent. moisture content showed a 24 per cent. increase in bulk over the dry volume of the sand. This effect was taken into account when proportioning the mixes, which were designed for dry materials. This point is sometimes ignored although it is an important cause of poor concrete, resulting in the use of too much water in an attempt to improve the poor workability of the concrete, which is caused by the lack of mortar.

Cement.—In view of the possibility of attack from acid and sulphates in the water used in the ash-sluicing system, "Ciment Fondu," manufactured by the Lafarge Aluminous Cement Co., Ltd., was used in the concrete work of the ash-sump and the foundation for the east chimney. In all other concrete work, the Cement Marketing Company's "Blue Circle" Portland cement was used.

Steel Reinforcement.—The reinforcement is of plain round mild-steel bar, complying with the British Standards Specification No. 15 for Structural Steel, Quality A.

Brickwork.—The bricks for the chimneys were manufactured by the Hepworth Iron Co., Ltd., and "Newhey" radial bricks were used for the facings.

Construction.

Excavation for the base and ash-sump of the east chimney was started in January, 1934, and was taken down to 19 feet 3 inches below the general ground-level, which was 85·0 O.D.; the last 10 feet were in red sandstone. Water was encountered below 75·0 O.D.,

particularly on the canal-arm side, to the extent of 800 gallons per hour, most of which entered along the horizontal bedding planes of the rock. In order to prevent this water mixing with the newly-placed concrete, galvanised corrugated-iron sheets were nailed against the rock sides in the bottom, and this caused the seepage to run down the faces into field-drains leading to a central sump.

The mix used in the concrete work of the base was 6 : 3 : 1 cwt. of "Ciment Fondu." This may be considered a fairly lean mix for reinforced concrete work, but cube strengths of from 3,500 to 4,330 pounds per square inch were obtained for this mix for 6-inch cubes after 7 days. The actual value which should be attached to these strengths, and also to the possibility that a 5 : 2½ : 1 cwt. Fondu mix might actually produce a weaker concrete, will be discussed in connection with the temperature-readings taken in this concrete. In order to minimize high temperatures in this concrete, the maximum lifts were kept down to 2 feet, and the concrete was flooded as soon as the final set had taken place.

The ratio of water to cement for the aluminous-cement concrete varied from about 0·85 to 0·95 by weight, which is relatively high in comparison with the standards of Portland cement. It was felt that, while this ratio was also higher than that necessary for workability, the slight loss in strength of the general mass would be preferable to the possibility of local sections of poor-quality concrete. This might otherwise have been anticipated on the face of the sump, due to the excessively rapid drying-out process, and to the incomplete hydration resulting from the expected high temperatures during the early life of the concrete.

The whole of the materials for the towers were handled by 5-ton cranes, with 100-foot jibs. For the east tower the crane was erected on the boiler-house roof, 100 feet above ground level, while the crane for the west tower was carried on a timber gabbert 100 feet high. Tubular steel scaffolding was used throughout the construction of both towers, and was designed to be entirely independent of the towers; after the second brace of the east tower had been concreted, the whole of the lower portion of the scaffolding was rearranged to permit the ash-grab to enter the tower and work over the sump while work on the upper portion of the tower was still proceeding.

It was specified that the whole of the shuttering of the exposed work above ground-level should be faced with steel, plywood, or similar material, in order to minimize board-marks. In the shuttering of the columns, No. 16 S.W.G. sheet-steel lining was used, and this proved satisfactory, each set of column-shuttering being used about ten times for each tower, with only minor attention between lifts.

For the bracing shuttering, sheet-tin facing was used, and although it needed careful handling, it was quite satisfactory.

In lifting the column-shuttering the cranes were used, and after a time it was possible to strike the shuttering, lift it and refix it in about three or four hours.

In certain cases the $1\frac{3}{8}$-inch diameter bars used for the main vertical reinforcing were 38 feet long, and the scaffolding had therefore to be kept about 40 feet in advance of the concreting. Before starting a new lift of reinforcing in the columns, a circular template made of four steel angles spliced together and notched to the spacing of the vertical bars, was set out over each column.

The vertical bars were lowered into position by the crane, and were automatically located by the notches in the template at the top and by the steel in the splice at the bottom. An extra stiffening template was generally used half-way up each lift of steel.

In the concrete work above ground level the concrete mix was $5 : 2\frac{1}{2} : 1$ cwt. Portland cement. Particular attention was paid to ratio of water to cement in this concrete, and allowing for the variable water content of the aggregate, this ratio was between 0·65 and 0·70 by weight. A slump of more than 2 inches was never recorded, the average cube strength being 3,000 pounds per square inch at 28 days, but no difficulty was experienced in working the concrete round the reinforcement; this may in part be due to the use of mechanical vibrators, of which two different types were used.

The first type of vibrator was an adaptation of the familiar pneumatic hammer; a rubber-faced piston delivered the blows to the shuttering, which transmitted the blow to the aggregate on the face of the concrete, forcing it back into the mass and bringing an excess of mortar to the face of the shuttering. While the action was mainly local, the effect in the main mass was still quite appreciable, and even if applied after hand tamping had been done, it was sufficient to drive air-bubbles out of the concrete.

The second type consisted of a small electric motor, on the shaft of which was an eccentric weight, the motor being fastened to the shuttering by a long chain. When running, considerable vibration is set up, and if the shuttering can stand up to the somewhat violent action, the concrete is very thoroughly consolidated. This vibrator was rather bulky to move about and fix, and there was a tendency, if left too long in one position, for excessive laitance to be caused on the surface.

A theodolite was used in preference to plumb-bobs for keeping the tower vertical, as the latter were impracticable owing to the long lengths and the complexity of the scaffolding. Two permanent stations were made on the axes of the tower and about 150 feet from

the centre. The theodolite was set up over each of these stations in turn and used to check centre-wires running up the four outside faces of the steel scaffolding.

Concreting on the east tower was completed in October, 1934, and the west tower was finished towards the end of February, 1935.

Experimental Work.

A considerable amount of research has recently been directed to the importance of creep and shrinkage in concrete. An extensive series of investigations has been undertaken at the Building Research Station on the allied problems of bond-resistance, shrinkage and creep.[1] The results of these researches carried considerable weight when the recommendations of the Reinforced-Concrete Structures Committee were drawn up. One of the most drastic of these recommendations, namely, that of a variable modular ratio, is the direct outcome of the research into creep.

The Barton towers were designed before the new recommendations were published, and it was while attempting to estimate the magnitude of the stresses due to shrinkage and creep that it was realized that, if any actual measurements of these effects could be obtained in the large members at Barton, they would provide a valuable supplement to those which had already been obtained on the specimens of more modest size at the Building Research Station.

Such steps were suggested by the consulting engineers to Dr. W. H. Glanville, M. Inst. C.E., of the Building Research Station, who readily agreed to take the necessary steps. The work was placed by him in the hands of Mr. D. A. G. Reid, Assoc. M. Inst. C.E., of the Manchester Municipal College of Technology, and late of the Building Research Station, with whom the Author had the pleasure of collaboration.

Temperature-Readings in the Newly-Placed Concrete.—The magnitude and effects of the temperature developed in newly-placed concrete have been discussed in two Papers.[2] In connection with these Papers, work was carried out on laboratory specimens and a method

[1] Dr. W. H. Glanville, Department of Scientific and Industrial Research, Building Research Station: Technical Paper No. 10, "Bond Stresses." Technical Paper No. 11, "Shrinkage Stresses." Technical Paper No. 12, "Creep or Flow of Concrete under Load." Also Dr. Oscar Faber, "Plastic Yield, Shrinkage, and Other Problems of Concrete, and their Effect on Design." Minutes of Proceedings Inst. C.E., vol. 225 (1927–28, Part I), p. 27.

[2] Department of Scientific and Industrial Research, Building Research Station; Dr. N. Davey, Technical Paper No. 14, "Influence of Temperature upon the Strength Development of Concrete." Also Dr. N. Davey and E. N. Fox, Technical Paper No. 15, "Temperature Rise in Hydrating Concrete."

was evolved for estimating the temperature-rise in large masses of concrete. The temperature-readings taken at Barton were intended to provide data to check these conclusions. Although it was well known that there was a considerable rise in temperature in cement mortars during setting and hardening, it is only within recent years that attention has been paid to its effects on the concrete and the structure as a whole.

The two main effects of the rise in temperature are :

(1) The effect on the actual strength of the concrete.

(2) The production of internal strains in the concrete.

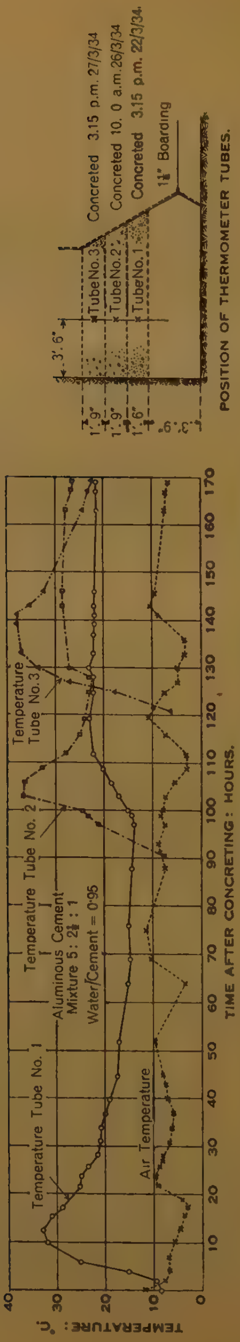
It has been found that, in cubes of Portland and rapid-hardening cements, a high curing-temperature produces a marked increase in strength, particularly in the early stages. In aluminous-cement concrete there is generally a slight increase in strength for moderate curing-temperatures, but there is a very marked falling off in strength for curing-temperatures much in excess of 20° C. As the rise in temperature in aluminous-cement concrete in the early stages is usually about double that in Portland-cement concrete, there is a danger of excessive temperatures being reached, even in small masses of concrete.

Fifteen thermometer tubes were placed in the aluminous-cement concrete, and readings of both air- and concrete-temperatures were taken over periods up to 10 days at 3-hour intervals, involving a total of some five hundred readings. By placing the tubes in the middle of the masses and also immediately under the shuttering, extensive records have been obtained. The temperature-records of layers of concrete, on which successive layers have been laid at fairly regular intervals, are of particular interest. (*Figs.* 7, p. 518.) In one case, where three layers had been placed successively, the temperature in the bottom layer remained at approximately 20° C. for 10 days, during which time the average air-temperature was only 7° C.

This comparatively high temperature must be considered as an upper limit, above which a distinct falling-off in the strength of the concrete may be expected, and explains the view expressed previously that in this case the 6 : 3 : 1 cwt. aluminous-cement concrete was preferable to a richer 5 : 2½ : 1 cwt. aluminous-cement concrete. It is probable that the loss in strength due to the high temperature would be greater than the expected increase in strength of the richer mix, as shown by test-cubes.

Temperature-records were also taken in the Portland-cement concrete of the upper structure of the towers (*Fig.* 8, p. 519), and, although these were of value in providing some indication of the curing conditions inside the members, which affect the strength of

Figs. 7.



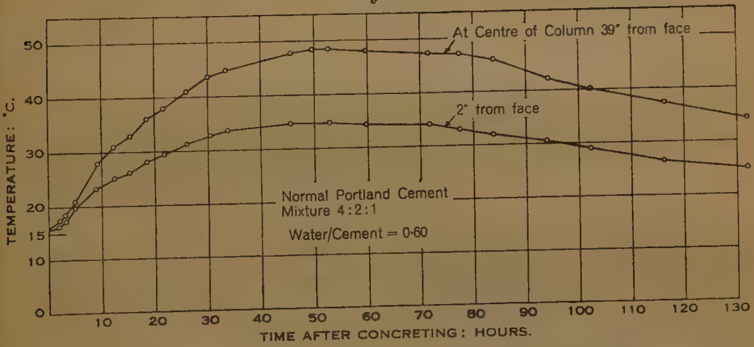
TEMPERATURE IN LAYERS OF CONCRETE.

the concrete, their chief importance is in the consideration of the internal stresses likely to be produced. This point will be discussed in connection with the strain-measurements.

Strain-Measurements.—Owing to questions of expense and to the short time available for experimental work, the apparatus was kept as simple as possible. It was decided to attempt to measure the total strains in the concrete columns, in both vertical and lateral directions, and later strain-gauges were also placed in the cross-bracings.

The gauges were constructed as follows. (*Figs.* 9, p. 520.) The outer tube of the lateral gauge was made from 1-inch gas barrel and was fitted with blank pipe-flanges at either end, its length being 6 feet 6 inches over the faces. A stainless steel plug was fitted into the end

Fig. 8.

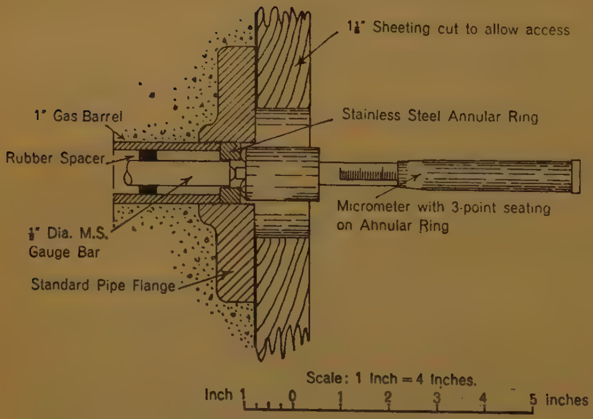


of the tube, and at the other end a stainless steel annular ring was screwed into the pipe. A steel rod, with hard steel balls let into each end, was arranged to slide in the annular ring, and to bear against the steel plug at the other end of the tube. The gauge was fitted into place when the shuttering was fixed and the end flanges were adjusted to bear against the shuttering. It was assumed that the outer tube would bond perfectly and would be strained with the concrete. Any change in length of the outer tube caused a movement of the annular ring with respect to the free end of the gauge-rod; this movement was measured by means of a micrometer with a special fitting at the end, which gave a three-point seating on the annular ring and allowed the adjustable centre-rod of the micrometer to bear against the gauge-rod. To obviate any errors due to the possibility of the face of the annular ring not being exactly normal to the gauge-rod, readings were taken with the micrometer in six evenly spaced positions around the ring, and the average of these readings was used as the final value.

The vertical gauges are similar in principle, but were made to provide access at one end from the face of the column, by means of a reduction-T screwed on to the end of the outer tube. Readings of the distance between the end of the internal gauge-rod and a steel ball let into a plug in the reduction-T were taken with an internal micrometer, and gave the strain in the outer tube.

Figs. 9.

SECTION OF LATERAL STRAIN GAUGE.



DETAIL AT "A" SHOWING METHOD OF TAKING READINGS.

These gauges were very robust and gave very little trouble in fixing. No readings were taken for the first set of strain-gauges until four days after concreting, when the shuttering was struck, but, in view of the comparatively large movements, it was arranged for the shuttering to be cut opposite the ends of the gauges fixed subsequently, and readings then commenced as soon as the concrete had set.

Before describing the results obtained from these strain-gauges, it may be as well to discuss some of the main factors which produce strains in concrete.

Generally, in a normal reinforced-concrete structure, there are at least four factors producing strains:

(1) The actual loads carried.

(2) Changes in temperature, which may be either—

(*a*) Due to changes in atmospheric temperature; or

(*b*) Due to temperature-rise in the concrete during hydration.

(3) Shrinkage movements.

(4) Creep, resulting from a state of stress set up by (1), (2) and/or (3).

In design it is usual to take into account (1) and probably (2*a*), and the main object of the experimental work at Barton may be described broadly as an attempt to measure the gross effect of (2*b*), (3) and (4).

The importance of the effect of the temperature-rise during hydration on the strength of the concrete has already been emphasized, but there remains the question of internal strain.

Although the temperatures encountered in a large mass of hydrating concrete are comparatively low, the strengths of the concrete at setting are also low, particularly in shear and tension. At Barton, temperatures of 140° F. have been recorded in the centres of the columns at times when the air temperature was between 60° F. and 70° F. It is therefore conceivable that temperature-differences occur in "green" concrete which are at least comparable with those taken into account for variations in atmospheric temperatures.

Recently, in America, it has been established that serious cracking has resulted from this cause, and this has led to some very exacting cement specifications [1] for the construction of large dams. One important point in these specifications is that, not only must a low total heat be evolved, but also the rate of evolution must be slow. There is some tendency, therefore, to abandon the modern finely-ground cements for more coarsely-ground materials, in which the action is slowed down.

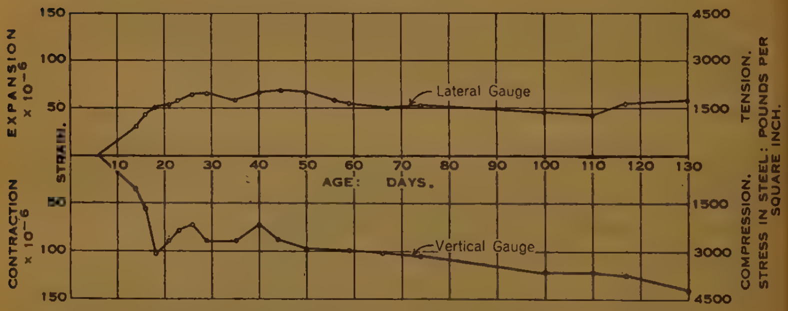
Shrinkage.—The shrinkage of concrete is familiar to all engineers, but it must be remembered that shrinkage is by no means inevitable, and can be very largely controlled by the curing conditions of the concrete. It has been found that the quicker the concrete dries out,

[1] Hoover Dam Cement Specification, Engineering News-Record, 1932, 109, pp. 358–360. Pine Canyon Dam—Special Low Heat Cement, Engineering News-Record, 1932, 109, pp. 410–411.

the greater the shrinkage, and also that expansion takes place when concrete is cured under water, or in conditions where there is no loss of moisture.

At Barton, the anticipated shrinkage was confirmed by the readings in the vertical strain-gauges, which were located close to the exposed face of the concrete. In the horizontal gauges, which were placed across the columns, expansion has taken place which is far in excess of that which would be anticipated—assuming a normal value of Poisson's ratio—from the combined stresses arising from the vertical loading. It would appear, therefore, that little drying-out takes place in the core, and that the average curing conditions across the column approximate to water-cured conditions. The recognition of this fact is probably the most important result of the experiments, and its effect in causing internal cracking may be at least as important

Fig. 10.



as that of the rise in temperature, particularly as the two effects are cumulative and do not tend to compensate one another, as would be the case with the shrinkage of the core.

The results obtained for a typical set of strain readings (*Fig. 10*) show that, after the maximum expansion is reached, a very slow shrinkage sets in, probably due to the slow drying-out of the core. It seems probable that some of the columns will pass through a stage when the lateral gauges will show exactly the same total length as when they were put in; it cannot, however, be assumed from this that there is no lateral stress, but rather that there are both local compressive and tensile stresses along the gauge, and that the algebraic sum of the strains is zero.

In connection with this expansion of the core, it may be of interest to consider what takes place at a construction-joint in the columns. Suppose a length of column has been concreted; within about three or four days the temperature in the core will have become a maximum, and will be greater than in the surface-layers, and therefore the

differential expansion will cause the top surface of the concrete to become slightly convex. At the same time, the core is expanding due to the curing conditions, and the convexity of the top surface is therefore further increased. At a construction joint, where two masses have been placed within a short time of each other, the expansions are taking place almost simultaneously, and if there were no reinforcement across the joint a circumferential crack would form, due to the comparative weakness of the joint and the tendency for convexity of the two adjacent faces of the concrete. In the case of the Barton columns the vertical steel reinforcement tends to prevent this crack, resulting in tension stresses in the steel and a compression area in the centre of the column. After a time, the concrete cools and the core begins to dry out, causing the tension in the steel and the compression in the concrete to diminish, and a point of great practical importance now arises. It is possible that the compression stresses over the central area of the joint may not only diminish to zero, but they may actually change sign and become tension stresses, which may be sufficient for the joint to fail over its central area, with the result that a definite crack is produced. If this actually does occur, the effective cross-section of the column is seriously reduced.

A special gauge was made to measure cracks of this character should they actually occur, but unfortunately the gauge was damaged during concreting and, owing to various difficulties, it has not been possible to carry out this test. It may be mentioned that, so far, no visible cracks have appeared in the work.

Creep.—In the Paper[1] by Dr. Faber, experiments are described in which the deflection of concrete beams under sustained constant loads was measured. It was found that a progressive increase in the deflection was shown, but that the rate of increase of the deflection continually decreased. In other words, if concrete is subjected to a continuous stress, the strain will continually increase with time, thus causing an apparent decrease in the modulus of elasticity. In a reinforced-concrete member which is under stress, two materials, steel and concrete, have to be considered; both are initially stressed in proportion to their respective elastic moduli, but the concrete, being more susceptible to creep than steel, tends to take less of the load, which is thereby transferred to the steel. This is the present theory on which column design is based, and in the recommendations of the Reinforced-Concrete Structures Committee it will be found that the stresses in the steel are based on its yield-

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[1] See footnote [1], p. 516.

point and that the instantaneous modular ratio of steel to concrete is increased.

This effect may be observed at Barton, and it is intended to take strain-measurements over as long a period as possible. At the present time it is difficult to distinguish between shrinkage and creep, but it may be mentioned that the strains were steadily, though very slowly, increasing at a date nine months after concreting.

Conclusion.

The new scheme for the disposal of the flue-gas at the Barton Power-Station was prepared by Mr. H. C. Lamb, M. Inst. C.E., Chief Engineer and Manager of the Manchester Corporation Electricity Department. The whole of the works described in this Paper were constructed under the supervision of the consulting engineers to the Electricity Department, Messrs. C. S. Allott & Son, represented by Mr. A. C. Dean, M.C., M.Sc., M. Inst. C.E. The contractors for the reinforced-concrete structures were Messrs. J. Gerrard & Sons, Ltd. The Author acted as resident engineer at the site during the work of construction.

The Author wishes to express his thanks to Mr. H. C. Lamb and Mr. A. C. Dean for permission to present this Paper.

The Council invite written communications on the foregoing Paper, which should be submitted not later than three months after the date of publication. Provided that there is a satisfactory response to this invitation it is proposed, in due course, to consider the question of publishing such communications, together with the Author's reply.

Paper No. 5026.

"Flow Between Piers: The Case of Small Loss of Head."

By Michael George Ionides, B.A.

(*Ordered by the Council to be published in abstract form only.*)

A formula which is frequently used for the determination of the flow between piers when the water-surface is unobstructed is:

$$Q = c'wd_2\sqrt{2g(E_1 - d_2)} \quad . \quad . \quad . \quad . \quad . \quad \text{(i)}$$

where

w denotes the total width of the waterway between the piers

E_1 ,, ,, upstream head above floor-level datum $= d_1 + \frac{v_1^2}{2g}$,

d_1 ,, ,, upstream depth,

d_2 ,, ,, downstream depth,

c' ,, a coefficient.

In recent work, it has been found by several investigators that the coefficient c' varies with the ratio of the waterway between the piers to the natural waterway in the channel (the "obstruction ratio"), and may exceed unity. The effect is that the coefficient increases with the obstruction ratio; since, however, the coefficient must be unity when the ratio is unity, it follows that it must attain a maximum, greater than unity, at some value of the ratio less than unity.

The expression may, however, be written in the form:—

$$Q = cWd_2\sqrt{2g(E_1 - d_2)} \quad . \quad . \quad . \quad . \quad . \quad \text{(ii)}$$

where W denotes the width of the natural waterway, so that

$$W = \frac{w}{r} \text{ approximately,}$$

r ,, ,, obstruction ratio,

and $c = c'r$.

In this case, the coefficient cannot exceed unity, at which value r is also unity, and it is therefore easier to deal with the experimental results.

With the object of examining the effect of the obstruction-ratio on this coefficient, the Author collected data from experiments on models, and investigated the problem theoretically.

For the case where the differences in level are small compared with the depths, the following expressions were determined theoretically:—

$$Q = KWd_2\sqrt{2g(E_1 - d_2)} \quad . \quad . \quad . \quad . \quad . \quad \text{(iii)}$$

where

$$K = \sqrt{\frac{r^2}{3r^2 - 4r + 2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(iv)}$$

The expression (iii) has the same form as (ii) above, and experimental values of the coefficient c were calculated both from the Author's data and from results obtained by Mr. H. Addison, M.Sc., Assoc. M. Inst. C.E.; these values agreed closely with the values of K calculated from formula (iv) for corresponding obstruction ratios, in spite of the wide variation in the other physical characteristics of the models used.

The conclusion is reached that, for the type of flow considered, and with certain defined types of structure, the obstruction ratio is the chief factor controlling the coefficient to be used, and that the formulas (iii) and (iv) may be used with confidence in practice, allowing a small margin of safety.

In practical problems of design, the discharge, depth and allowable afflux are usually known, and the width of waterway has to be determined. Formula (iii) may be used to find the necessary value of K, from which the value of the obstruction ratio can be obtained from formula (iv). Hence, the width necessary between the piers is rW, where W is the natural width of the stream, plus a small margin of safety.

The formulas are applicable under the following conditions:

(1) (*a*) The differences in level of the water-surface are small compared with the depths.
  (*b*) The velocity of approach is taken as the velocity at the point where the upstream depth is measured.
  (*c*) The water-surface is unobstructed.

(2) The piers are assumed to be approximately stream-lined, with no fluming on the discharge side.

(3) If the channel is not rectangular, the width taken should be the average of the widths at the point where the depths are measured.

(4) If the approach- and tail-channels are of different widths, the approach-channel should be assumed to be gently flumed in to the same width as the tail-channel, and Bernoulli's theorem applied to determine the theoretical level on the upstream side of the structure.

(5) If the sill of the sluice is higher than the bed of the channel, the bed should be assumed to be gently flumed up to the level of the sill, and Bernoulli's theorem applied as in (4) above.

NOTE.

ENGINEERING RESEARCH.

NOTES on the work of the Building Research Station and the Road Research Laboratory of the Department of Scientific and Industrial Research appear below. These follow the notes on the work of the Geological Survey and Museum and the Forest Products Research Laboratory which appeared in the December Journal.

THE WORK OF THE BUILDING RESEARCH STATION.

The Building Research Station was established by the Department of Scientific and Industrial Research to provide a State service for the building industry. It embraces in its scope all building research problems other than those specifically concerned with timber, which are dealt with at the Department's Forest Products Research Laboratory.

While much work that is of engineering interest is necessarily carried out at the Station, yet in formulating its programme and in developing the types of service it renders, the primary concern has, naturally, been to meet the requirements of the building industry. The extent and ramifications of the building industry—using the term in its widest sense—render it necessary for the Station to cover a wide ground, giving rise to problems of considerable variety. This is due to the large range of materials employed in building, and from the fact that the Station is concerned not only with their behaviour in use but also, so far as may be necessary, with their manufacture.

No attempt will be made here either to indicate the range of work which has been attempted at the Station or to summarize the results obtained, apart from a reference to certain investigations of interest to the engineer. Full information on that subject is given in the various reports published by the Station. A brief description of its main activities will, however, be given, in order to furnish a guide to the various ways in which its assistance is placed at the disposal of the building industry.

The character of the work of the Station may be described broadly under the following heads :—

(1) General research.
(2) Co-operative research.
(3) Special investigations.
(4) Enquiries.
(5) Publications.

(1) *General Research.*

Under this heading is comprised work on the fundamental properties of materials, either from the chemical or engineering standpoint, work on problems of construction, and work on problems associated more directly with the comfort and appointments of buildings already in use, such as problems of heating and ventilation. The general aim of the work is to provide a basis for the development of a real science of building, since building has in the past been guided more by tradition than by scientific knowledge.

(2) *Co-operative Research.*

Co-operative research undertaken at the Station should not be necessarily differentiated from problems of general research purely on account of the nature of the work undertaken; the difference lies rather in the fact that the subjects of co-operative research are identifiable with particular interests. For example, an association of manufacturers concerned with a particular material may express a desire to collaborate with the Station in the investigation of problems with which they are confronted, or a professional institution may wish to suggest matters for co-operative investigation. The Station is always ready to consider proposals for research in association with outside bodies, the cost of the work being shared on an agreed basis. Examples of such work are provided by the research on pile driving and earth pressures now being arranged in co-operation with The Institution of Civil Engineers through their Research Committee. Another example, one of co-operation with an association of manufacturers, is the research on cast concrete products undertaken in conjunction with the Cast Concrete Products Association.

(3) *Special Investigations.*

Individual firms frequently require an independent report on the properties of their products. The Station undertakes, on payment, the investigations required and issues reports on the suitability of the materials for building purposes. Such work may be carried out on products in actual use and on materials in course of development, opportunities of aiding the development of improved products in this way being particularly welcomed by the Station. The reports issued are available, under certain conditions, for use for advertising purposes. It should be noted, however, that the activities of the Station in this direction do not embrace work such as would normally be undertaken by a consultant. Arrangements exist whereby standardized tests on materials submitted for investigation, which

are required by the Station for the purposes of reports, are referred to consultants on a panel, approved on the recommendation of a committee comprising the Presidents of the professional Institutions.

(4) *Enquiries.*

Closely associated with the section dealing with special investigations is a special section of the Station devoted to the handling of the numerous enquiries received concerning building materials and processes. In cases where the information is available from existing records no charge is normally made, but where laboratory work or a visit to a site is required to furnish an answer, a fee to cover the cost is quoted. That the service rendered in this way is appreciated is indicated by the rapid increase in the number of enquiries. In 1934, the Station dealt with two thousand and eighty-nine enquiries and special investigations; this represents an increase of five hundred and sixty-three over the previous year.

The work of this enquiry-section includes references on building failures, for the Station is ready to assist, in appropriate cases, in dealing with building troubles by investigations, designed both to establish the cause and to suggest a remedy.

(5) *Publications.*

The Station reserves the right to publish the results of investigations whether they fall into the category of general research, co-operative research, or special investigations, though in the last two cases publication is subject to prior consultation with the outside bodies concerned. The publications take the following forms :—

Annual Reports, which summarise the progress of the work of the Station from year to year.

Technical Papers, which are essentially scientific accounts of researches on particular problems, and which are intended for the technically-qualified rather than for the lay reader.

Special Reports, in which groups of associated problems, such as studies in connection with a particular product, are dealt with in a comprehensive manner for the information not only of the scientific worker but also of the manufacturer or user.

Bulletins, which represent brief summaries of information on the selected topic, written so far as possible in non-technical language, and intended to set out the results obtained and how they should be applied, rather than the manner in which the results were obtained.

Building Science Abstracts. The survey of literature dealing with building problems is an essential feature of the organization.

Abstracts of this literature are published monthly under the title "Building Science Abstracts."

The above publications are issued through His Majesty's Stationery Office. From time to time papers are also issued to the scientific or technical press, while every month a selection of the enquiries received at the Station, and the answers given, are communicated to various journals for publication in the form of Notes from the Information Bureau of the Station. Considerable importance is, in fact, attached to efforts towards making known the information at the disposal of the Station, for it is realized that the usefulness of the organization must depend ultimately on the extent to which its work finds application in practice. A further development of the methods of disseminating the results has been brought about recently by arrangements to hold exhibitions of its work from time to time at various centres, as opportunity offers. The first was held at Bradford in February, 1935 and the second at Manchester in October of the same year.

Engineering Research.

Engineering research recently carried out, and now in hand at the Building Research Station, includes investigation of the following subjects :—

(1) Concrete and reinforced concrete.
(2) High-tensile structural steel.
(3) Vibrations in buildings.
(4) The development of methods of measuring stresses in existing structures.
(5) Deterioration of structures exposed to sea-action.
(6) Brickwork masonry.
(7) The fire-resistance of structures and structural elements.
(8) Foundations.

(1) Concrete and Reinforced Concrete.

(a) *Methods of Testing Cement.* The work on concrete has included an investigation into the best form of test for measuring the concrete-making qualities of cement. This has been done in connection with the British Standards Institution Committee concerned with the revision of the Portland Cement Specification.

(b) *Workability and Grading of Aggregates.* An investigation is being made of the workability and grading of concrete aggregates. This work has involved the development of a special test, known as the "compacting test," for measuring workability. Amongst

other matters of interest it has shown conclusively that the best proportions for concrete depend on the workability that is required for the particular work in hand.

(c) *Reinforced-Concrete Piles.* In co-operation with the Federation of Civil Engineering Contractors an investigation has been made of the resistance of reinforced-concrete piles to the stresses imposed during driving. A Paper on this subject was read at The Institution on 12 November and the work is being continued in co-operation with the Research Committee.

Further studies are being made of the various kinds of head-packing materials available, and of the various factors influencing the impact-strength of concrete.

(d) *The Temperature Effects in Concrete.* Studies have been made of the temperature effects in concrete arising both from the evolution of heat during hydration of the cement and from external weather-conditions. The work has been described in various technical papers published by the Building Research Station and in articles sent to the technical press.

(e) *Reinforced Concrete.* Several problems are being studied in co-operation with the Reinforced-Concrete Association. These problems include :—

The redistribution of bending-movements in structures due to inelastic movement of the concrete and the steel.

The cracking of reinforced concrete under conditions of complete and incomplete restraint.

The effect of the size of cracks on the corrosion of the steel reinforcement.

The bond and anchorage of steel reinforcement. The behaviour of long columns.

For the Road Research Board, a study is being made of the behaviour of reinforced-concrete road-slabs under static loading-conditions.

(2) High-Tensile Structural Steel.

Several special investigations of considerable scope have been made for steel manufacturers to determine the suitability of various high-tensile steels for use in buildings.

(3) Vibrations in Buildings.

A study is being made of the effect of vibrations in buildings. It has been shown, theoretically, that there is very little likelihood of damage arising from traffic vibrations except in the case of extremely weak structural members, such as brick piers built in very friable lime mortar.

(4) The Development of Methods of Measuring Stresses in Existing Structures.

In order to examine the structural stability of various old buildings which have been suspected of being unsafe, a method has been devised of measuring the stresses in the structure. The method involves cutting out small specimens from the structure and measuring the release of strain that occurs as a result. The cost of the design of the apparatus was borne jointly by Sir Basil Mott and the Station.

(5) Deterioration of Structures Exposed to Sea-Action.

In collaboration with The Institution of Civil Engineers, the Station has undertaken a lengthy series of experiments on the action of sea-water on reinforced-concrete piles. In the first place, the work was partly financed from the funds at the disposal of the Sea-Action Committee of The Institution.

(6) Brickwork Masonry.

In connection with the specification of suitable bearing pressures for brickwork built in compo mortars, tests are being carried out on a series of piers representing the range of compo mortars likely to be used in practice.

(7) The Fire-Resistance of Structures and Structural Elements.

The Building Research Station has collaborated with the Fire Offices' Committee in the design and equipment of their new Fire Testing Station at Boreham Wood. It was opened on 26 November, 1935, and tests will be carried out by the Building Research Station, both to grade existing materials and methods of construction and also to carry out tests in accordance with British Standard Specification No. 476 (Standard Definitions for Fire Resistance).

(8) Foundations.

The work of Professor Jenkin at the Station is being continued and extended. The various tests for classifying soils are being carried out as a routine matter and new tests are being devised. Work in connection with structures that have failed, and with the measurement of settlements in buildings in course of erection, is also in progress.

THE WORK OF THE ROAD RESEARCH LABORATORY.

Statutory authority to conduct experimental work was conferred on the Ministry of Transport by the Roads Improvement Act of 1925. Under the provisions of this Act, the Roads Department of the Ministry were responsible for the construction and equipment at Harmondsworth, Middlesex, of an Experimental Station, where laboratory tests could be made in association with the experimental work carried out on roads under normal traffic-conditions. Work at the Station began in April, 1930, and continued there under the direct control of the Ministry until 31 March, 1933. On that date the duty of directing and supervising the work of the Station (now the Road Research Laboratory) was transferred to the Department of Scientific and Industrial Research.

The Minister of Transport had the advice of a Technical Advisory Committee, representative of Highway-Authorities and organizations interested in road-problems. So far as they concerned laboratory-work on road-materials and construction, the functions exercised by this Committee have been transferred to a Road Research Board appointed by the Committee of the Privy Council for Scientific and Industrial Research. In order to obtain continuity, the Road Research Board includes several former members of the Ministry of Transport Technical Advisory Committee, and the Chairman of the Board is the Chief Engineer of the Ministry of Transport.

Part of the programme of the Ministry of Transport had consisted of full-scale tests, in co-operation with local highway-authorities, of road-materials and of different types of construction which were to be carried out in various parts of the country. The necessity for associating these tests with laboratory-work had been fully recognized, and samples of all materials used were regularly examined at the Laboratory; in addition, tests were made on the finished road. Under the scheme now in operation, the Ministry of Transport remains responsible for the conduct of full-scale tests outside the Road Research Laboratory, and continues to be the channel of communication with the various highway-authorities.

Arrangements have been made for all laboratory-work in connection with the Ministry of Transport full-scale tests to be continued at the Road Research Laboratory, very close technical co-operation being maintained between the Ministry of Transport and the Laboratory.

General Research.

Under the scheme of road research the whole of the laboratory-resources of the Department of Scientific and Industrial Research

are available. The official headquarters are at the Road Research Laboratory, but some sections of the programme are being carried out at the National Physical Laboratory and at the Building Research Station, whilst close contact is maintained with the work of the Chemical Research Laboratory on tars for use as binders in road-construction, and with other laboratories of the Department. Unless otherwise stated, the items of work described here are carried out at the Road Research Laboratory.

The general problem of road research can be divided into three main sections :—

(1) Road-construction and design.
(2) Road-usage.
(3) Development of special testing-apparatus.

(1) Road-Construction and Design.

The materials and processes employed in road-construction are dealt with under the headings :—

(a) *Soil Physics*, or research into those factors which produce deformation of a subsoil, is carried out for the Board at the Building Research Station. The object of the work is to provide the engineer with data which will give him a better understanding of the subsoil conditions.

(b) *Aggregates, Fillers, and Binders.* These form the basis of most types of road-construction and their physical, mechanical, and chemical properties are investigated.

(c) *Concrete and Reinforced Concrete* (*Surfacings and Foundations*). Much of the work on cement and concrete is common to both the building- and road-industries. Research on the fundamental properties of concrete is being continued at the Building Research Station, while the aspects of the subjects of particular importance in road-construction, namely joints and cracks in slabs, and methods of field-control, are being investigated at the Road Research Laboratory.

(d) *Bituminous Roads* (*Surfacings and Foundations*). Little information is available on any methods of design for bituminous mixtures which are based on fundamental principles. Most of the "tests" suggested are of an arbitrary nature and lack correlation with actual road-behaviour. The problem is being attacked at the Road Research Laboratory by means of small-scale laboratory-tests associated with tests in road-machines in which "traffic" conditions are accelerated. Surface-dressing can be considered as a particular type of road-surface treatment.

Research work on the mechanical and physical properties of tars

and pitches, and mixtures of tars and pitches with aggregates, is carried out for the Road Tar Research Committee, on which representatives of the British Road Tar Association co-operate with those of the Department.

(2) Road-Usage.

The major forces on the road, apart from those due to atmospheric conditions, are supplied by vehicles, and the road must be designed to resist these forces.

This section of the research, therefore, deals with an estimation of loads applied to roads, together with other requirements, such as slipperiness and deformation, associated with the use of the road. That section of the work dealing with the factors in vehicle-design and usage which produce damage to the road is carried out at the National Physical Laboratory in co-operation with the Institution of Automobile Engineers (Research and Standardisation Committee).

(3) Development of Special Testing-Apparatus.

Apparatus of new or improved design is necessary for most researches, and in some cases the whole investigation hinges upon the provision of suitable equipment. It is convenient to deal with each of these items under a separate heading. The apparatus already in use consists of

(*a*) Vehicles for determining the skidding-characteristics of the road-surface.

(*b*) Apparatus for measuring the impact of wheels on roads.

(*c*) Core-drill for cutting samples from concrete or other roads for analysis.

(*d*) Road-testing machines for determining the durability of road-surfaces. Two machines are in use which have mean diameters of 5 feet 3 inches and 38 feet respectively. A third machine, having a mean diameter of 110 feet, is nearing completion.

Apparatus under construction includes a machine for making large test-pieces of bituminous materials under rolling compaction, and a 16-wheel machine for measuring the surface-irregularities of roads.

Co-operative Research.

As stated earlier, investigations are in progress in co-operation with the Road Tar Research Committee and the Research Section of the Institution of Automobile Engineers. The Laboratory is

always ready to consider proposals for research in association with outside bodies.

Publications.

The publications of the Laboratory take the following form :—

(1) *An Annual Report* of the Road Research Board. This summarises the progress of the work from year to year. The first report for the period ending 31 March, 1935, has been published.

(2) *Scientific Memoirs.* These will deal with items which are purely of scientific interest and will be offered for publication to scientific societies.

(3) *Special Reports.* At the commencement of a specific item of research it is necessary to bring together, in a suitable form, all information on the subject, together with a reasoned commentary on such information. This is done in a special report which may not, therefore, include any results of work carried out at the Road Research Laboratory.

(4) *Technical Papers.* These papers give full information on work carried out on any specific subject. They are intended for the technical rather than the lay reader.

(5) *Bulletins.* These give in simple language the practical applications of work carried out on any subject which has been described in a technical paper.

(6) *Road Abstracts.* A survey of current literature is communicated monthly to the technical press and published also as a special supplement to the Journal of the Institution of Municipal and County Engineers.

Items (3) to (6) are published jointly by the Department of Scientific and Industrial Research and the Ministry of Transport.

OBITUARY.

WILLIAM FERGUSON, M.A., B.A.I. (Dublin), was born on the 15th June, 1852, at 26, Lloyd Square, London, and died at Wellington, New Zealand, on the 20th June, 1935. He served a pupilage with Messrs. Courtenay, Stephens & Co., Mechanical Engineers, Dublin, and then became Chief Draughtsman to Messrs. Ross, Walpole and Stephens, Dublin. From 1873 to 1877 he pursued courses of study at Trinity College and the Royal College of Science, Dublin; and for the last two years of the period he worked as assistant to Mr. John Bower, M. Inst. C.E., on waterworks and other contracts. After a short time as Chief Draughtsman to the Hydraulic Engineering Company, Chester, Mr. Ferguson became, in 1879, Assistant to the Professor of Civil Engineering at Trinity College, Dublin, and during 1882 acted as locum tenens for six months. In 1883 he sailed for Dunedin, New Zealand, and in May 1884, was appointed Engineer and Secretary (and subsequently Treasurer) to the Wellington Harbour Board. He resigned from this position in February, 1908, but after a short leave of absence was appointed Consulting Engineer to the Board for five years. During his time with the Board he was responsible for the complete re-equipment of the harbour with up-to-date hydraulic cranes and other plant for the rapid handling of cargo.

From May, 1908 to the end of February, 1917, he acted for the first year as General Manager, and subsequently as Managing Director, to the Wellington Gas Company, Ltd., during which time new works were designed and erected for the supply of Greater Wellington. Mr. Ferguson retired from the Directorate of the Gas Company and other offices held by him at that time in order to devote his whole attention to war work, having been appointed by the N.Z. Government to the honorary position of Chairman of the National Efficiency Board.

From 1910 until 1924 Mr. Ferguson acted as chairman or member of many important commissions and was also appointed as Engineering Member of the Board of Public Health. He was a Member of the Council of the Victoria University College for many years. He was a Life Member of the Royal Dublin Society, a Member of the

Institution of Mechanical Engineers, a Foundation Member of the N.Z. Society of Civil Engineers and President for the year 1919–20.

Mr. Ferguson was elected an Associate Member of The Institution on the 7th December, 1880, and transferred to the class of Member on the 16th May, 1893. He was from 1912 to 1914 the representative Member of Council in New Zealand and for many years acted as Member and Chairman of the Local Advisory Committee.

He married in 1890 Mary Louisa, daughter of Mr. William Moorhouse, who died in 1930, and by whom he had one son and one daughter.

ERNEST PRESCOT HILL, the elder son of Mr. G. H. Hill, a former Vice-President Inst. C.E., was born at Altrincham on the 16th June, 1861, and died on the 18th June, 1935, at Bournemouth. After being educated at Upton House, Slough and Eton, he was from 1879 to 1883 a pupil of Mr. J. F. La Trobe Bateman, Past President Inst. C.E., and in 1885 became a Resident Engineer for Messrs. Bateman and Hill upon extensions of the Cheltenham waterworks, including the construction of the Dowdeswell reservoir. From 1886 to 1891 he was one of the Resident Engineers in the Lake District for his father upon the works of the Thirlmere scheme, including at the northern end the dams whereby that lake became a reservoir, and at the southern end the aqueduct towards Manchester.

In 1891 he was transferred to London in order that he might be associated with his father's practice there, the headquarters of the firm, however, still remaining in Manchester, where the firm of Messrs. G. H. Hill and Sons were created in 1894 with his younger brother also as a partner. During the course of his career, Mr. E. P. Hill carried out various waterworks, including the Embsay reservoir near Skipton, the Ystradfellte reservoir in South Wales, besides sundry work at other places including Huddersfield, Newport, Mon., and Exmouth. He had an extensive consulting practice, in the course of which he went out to South Africa to advise Capetown with regard to its waterworks.

After the death of his father, on the 4th March, 1919, Mr. E. P. Hill dissolved the partnership with his brother and took over that part of the practice which centred on London, and pursued it until his retirement. He contributed short Papers on "The Resultant Thrust of Fluid-Pressure in Bend-Pipes," and "Yield of Catchment Areas," which were published in vols. cxiii and clxvii respectively of the Minutes of Proceedings, Inst. C.E.

Mr. Hill was elected an Associate Member on the 1st December, 1891, and transferred to the class of Members on the 16th January, 1894. He served on the Council of The Institution from 1919 to 1928. He was also a Member of the Royal Institution.

He married in April, 1887, E. Kathleen Lucy, daughter of the Rev. Pemberton Bartlett, Rector of Exbury, Hants, who survives him.

SIR HUGH REID, Bart., C.B.E., LL.D., son of Mr. James Reid of Auchterarder, Perthshire, was born on the 9th February, 1860, in Manchester, and died on the 7th July, 1935, at Belmont, Springburn, Glasgow.

From 1876 to 1881 he served as an apprentice with the Hyde Park Locomotive Works of Messrs. Neilson & Co., at Glasgow, and later pursued a course of study at Glasgow University.

His whole working life was spent with Messrs. Neilson Reid and Company and the North British Locomotive Company, Limited. He became a partner of the former with his three brothers in 1893, and on the death of his father, Mr. James Reid, M. Inst. C.E., in 1894, he assumed the position of senior partner with the firm.

In 1903, an amalgamation of interests between the Hyde Park Works, the Queen's Park Works, Polmadie, Glasgow, and the Atlas Works, Springburn, was effected, and the North British Locomotive Company, as it is now known, was constituted, with Sir Hugh as Deputy-Chairman and Chief Managing Director.

Sir Hugh Reid was joint inventor in 1910 of the "Reid-Ramsay" steam-turbine electric-locomotive, which underwent some trials but was not actually placed in service. A second locomotive embodying a turbine was exhibited at the British Empire Exhibition in 1924, but in this case power was transmitted to the axles through double-reduction gearing.

During the war he was a member of the Management Board for the supply of munitions in Glasgow and West Scotland, and was also closely associated with Red Cross work in that area. He received the Commandership of the Order of the British Empire for his services in that connection. He was created a baronet in 1922. He took a leading part in the life of Glasgow and was elected Lord Dean of Guild, and in 1917 received the freedom of the city.

From 1925 to 1929 he served as President of the Royal Glasgow Institute of Fine Arts. His University honoured his services to the City of Glasgow by conferring upon him in 1929 the honorary degree

of Doctor of Laws. He held the Volunteer Decoration and always took a lively interest in the work of the Territorial Army Association as Vice-Chairman. He was Deputy-Lieutenant of the County of the City of Glasgow, and Brigadier of the Royal Company of Archers, King's Bodyguard for Scotland.

Sir Hugh was elected a Member of The Institution in 1897. He served on the Council from 1922 until 1928.

In 1888 he married Marion, youngest daughter of the late Mr. John Bell, of Craigview, Prestwick, Ayrshire. She died in 1913. There were three sons and one daughter of the marriage. Sir Hugh is succeeded in the title by his elder surviving son, Douglas Neilson, born in 1898, his eldest son, Captain James Reid, 10th Bn. H.L.I., being killed in action at the Battle of Loos, 25th September, 1915.

CORRESPONDENCE

ON

PAPERS PUBLISHED IN NOVEMBER AND DECEMBER 1935 AND JANUARY 1936 JOURNALS.

VOLUME 1, 1935–36.

Paper No. 5027.[1]

"Sudan Railways, 1925–1935."

By Herbert Duncombe Bindley, M. Inst. C.E.

Correspondence.

Mr. J. E. Embleton observed that mention had been made on p. 60 of the trouble experienced with bridges founded on "cotton soil," due to the piers having been forced out of alignment or level owing to the expansion of the soil after rains. It would be interesting to know what kind of foundation had been employed. Presumably those piers were founded near the ground surface. Was there any reason why they should not have been taken to a considerable depth, in an attempt to get down to more or less stable soil below the surface? On the Bengal–Nagpur Railway, where large areas of black cotton soil occurred, foundations for bridges were taken down to good soil which was usually found at about 15 feet to 25 feet below ground level. Mr. Embleton.

Had any trouble resulted from the masonry of the piers or abutments cracking, either horizontally or vertically, and was reinforced concrete used to any extent in those structures, either in the foundations or the superstructure?

It appeared from p. 56 that there were sections of the track entirely ballasted with "cotton soil," where steel pea-pod sleepers had been employed. Success had also been achieved by filling over the cotton soil with disintegrated granite ballast, which had the effect of forming a waterproof surface preventing percolation into the soil bank. It would be interesting to know

(a) the frequency and method of packing required at the joints, especially during the rains, when the soil was water-logged;

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[1] p. 49 (November).

Mr. Embleton.

(*b*) whether any trouble had occurred from rusting of the steel sleepers, or from the fastenings becoming caked with mud?

What size and depth of granite ballast surfacing had been found successful on cotton banks? Apparently the top surfacing had been taken right across the whole width of the formation. Had any attempts been made to drain the banks by a system of "fan" drains, or to use "boulder drains" at spaced intervals across the bank?

It was noted that rail and flange lubricators were being tried on curves, in order to reduce the excessive wear on rails; particulars of the lubricators used would be of interest.

Mr. Farquharson.

Mr. J. R. FARQUHARSON observed that, with an average section under each track supervisor of 240 kilometres, and with each section divided into ten lengths of 24 kilometres, the organization certainly appeared simple, but ten subordinates was a large number to control directly and 24 kilometres was a long length for one gang. It would be generally acknowledged that the aim of a permanent-way organization was to maintain at the lowest possible cost the track and formation to a pre-determined standard to suit the traffic passing. Two main points required consideration—the optimum gang length and the form of the supervision. Some of the factors affecting the former were:—

(i) the distance which the gang could economically walk (or go by other means) to work;
(ii) the number of labourers that the average headman could control; and
(iii) the local characteristics affecting the amount of maintenance work.

The form of organization was affected by:—

(*a*) the ability of the average gang headman;
(*b*) the means by which the supervisor could inspect the track; and
(*c*) the ability of various classes of track supervisors available.

It would be interesting if the Author could give some information on those or similar points which had influenced him in forming the organization described.

Mr. Ketley.

Mr. H. C. KETLEY remarked that, although special study had been given to making buildings termite-proof, and mention had been made of various methods of construction employed, no description of the proofing methods used had been given. Some particulars of those methods and their results would be interesting.

In all parts of Nigeria both subterranean and non-subterranean termites were serious pests. Elimination of timber in the buildings was, of course, effective against both forms of termite, but it was felt

that, in a country so richly provided with excellent hard timbers, attempts should be directed rather towards proofing the timber against attack than to eliminating it from buildings and using imported cement and steel as substitutes. Undoubtedly a building could be permanently proofed against the entry of the subterranean termites by inserting one or more termite-proof courses (such as copper sheet) in all walls, but that was only effective if carried out with great care. The lower sections of door-frames and similar parts would also have to be of concrete, as the lower termite-proof course was usually fixed about 6 or 9 inches above floor level. In Nigeria, however, it was difficult to guarantee that the necessary care in supervision would be exercised to ensure the effectiveness of that method. There was also a danger that termites would obtain entry if the building were neglected at any time. Again, such methods were useless as safeguards against the non-subterranean termite, whose attacks were serious in most parts of Nigeria. Mr. Ketley.

A timber locally called Iroko (*Chlorophora excelsa*), if of first-class quality and well seasoned, appeared to be immune from the attack of termites for at least 15 years, and there was a plentiful supply of it at reasonable cost in most parts of Nigeria. It was a strong and beautiful wood and was reasonably easily worked. It seemed likely that future developments in termite-proofing in Nigeria would be directed to the use of suitably-selected Iroko and to proofing other timbers with chemicals, creosote, and proprietary by-products, although the treatment of timber with such products had so far not been successful after the lapse of a few years.

It would be interesting if the Author could give the results of his experience of the methods described above, if they had been tried in the Sudan, or of other methods.

Mr. J. N. D. La Touche observed that the Author did not state how the staggering of rail-joints was arranged, but he presumed that it was in the usual manner with the joints in one line of rails opposite the middles of the rails in the other line. That had been tried on the Dhond–Manmad Railway (now part of the Great Indian Peninsular Railway), but had had to be altered on account of the dangerous swaying set up at certain speeds. A somewhat different plan had been adopted by Mr. W. R. Haughton, M. Inst. C.E., on the Ranaghat–Murshidabad extension of the Eastern Bengal State Railway; the joint on one side was laid with a lead of 2 feet 6 inches over that on the other, that being approximately the length of a fishplate plus the width of a sleeper. That gave a very smooth and silent road, and even when the bank was soft, with earth packing, there was no tendency to sway. On curves when the leading joint was on the outside the lead was allowed to decrease to 2 feet before a rail was Mr. La Touche.

Mr. La Touche. cut to readjust it; when the leading joint was on the inside, the lead was reduced to 2 feet at the springing.

In his opinion cast-iron plate sleepers were much to be preferred to steel "pea-pods," as, even with reinforced lugs, the keys got loose and the trough sleepers were more difficult to pack. The plates were easily packed and had their whole bearing area under the rail where it was wanted. Slack on curves could also be better adjusted. If a trough sleeper were damaged, the rail had to be taken out before the sleeper could be extracted, unless the old and (he believed) now obsolete gib-and-cotter fastening were used. A damaged plate could be taken out and replaced by a sound one without disturbing the rails. There were six different types of steel trough sleeper on the metre-gauge section of the Eastern Bengal State Railway, but not one of them had proved really satisfactory.

The Author. The AUTHOR, in reply, observed that the staggering of rail-joints on the Sudan Railways had followed the normal system, the joints in one line of rails being opposite the middles of the rail-lengths in the other.

The organization of track maintenance had been built up to suit the conditions of the country, which was waterless all the year round in the northern part and waterless for nine months of the year in the southern part through which the railway ran. Permanent-way gangs could therefore only be maintained at stations, and were entirely dependent on train services for their food and water in most places. They proceeded to and from their daily work by means of mechanical trolleys. On an average section of 24 kilometres between stations the farthest point of their work was therefore 12 kilometres from their home station; actually, on some of the desert sections the stations were as far apart as 30 to 40 kilometres and section gangs in that part had therefore to maintain 15 to 20 kilometres of track on each side of their stations. The average section gang was eight to ten platelayers, according to the length of the section, type of track, kind of soil formation, and other local conditions. Track-supervisors were provided with mechanical trollies, but these were being gradually replaced by motor gang trollies to enable the supervisors to cover more ground. They were allotted travelling saloons, and spent 2 to 3 days at each station, so they were therefore enabled to inspect a part of each section gang's work at least once a month. The use of motor gang trollies enabled that inspection to be increased considerably, as the supervisor was able to travel farther afield from each halting place.

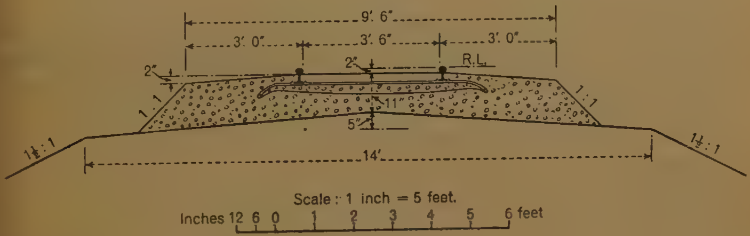
With regard to cotton soil filling, once the rains had started no lifting or packing of the track was possible at all; that condition continued roughly from the end of June to the beginning of

The Author.

November, the period varying slightly from year to year, being dependent on how early the rains started and how intense they were. On certain sections of the line trouble had occurred through steel sleepers rusting, and had generally been traced to the presence of salts in the soil. Trouble from the fastenings becoming caked with mud was not prevalent as a rule, as the track was not disturbed during the wet season. Ballasting with disintegrated granite was done to a depth of approximately 1 foot, as shown in *Fig. 5*. No attempt had been made to drain the banks other than by shallow surface-drains to take off top water and allow it to pass under the rail; two such shallow cross drains were made to every rail length. Boulder drains had not been used, as experience had shown that it was essential to avoid allowing water to enter the bank.

The type of rail and flange lubricator used was the "Surge," manufactured by the P. & M. Company.

Fig. 5.



With regard to the foundations for 15-foot span bridges, mass concrete had been used, and, as far as was known, in the earlier days of the Sudan Railways they had not always been taken down to any considerable depth. On the Gedaref extension underlying and more stable strata were found in most cases at a reasonable depth of 8 to 15 feet below ground level. Vertical cracking had occurred between abutments and wing-walls, but little trouble had been occasioned through abutments or piers cracking either vertically or horizontally. No reinforced concrete had been used in the past, but in more recent years certain bridges over canals, in the Gezira and on the Kassala line, had been built with reinforced-concrete foundations in the form of a raft. The reinforcement had been carried up into the abutments and horizontally between the abutments and the wing-walls in such a way as to counteract cracking where that had previously been found to take place.

With regard to the endeavours made to render buildings more termite-proof, the subterranean termites were the only species really

The Author. prevalent that gave any trouble. In some of the older houses the brickwork had been built in lime mortar and started off the top of the concrete foundation. It had been found that the termites made their way up inside those walls, and that had been overcome by constructing a granite masonry found in cement mortar up to 1 foot minimum above ground level and commencing the brickwork off the top of that masonry found, which at the same time eliminated dampness from the wall. In the interior the concrete floor was made to recess into the wall, thus minimizing the risk of a space being left between the floor and the wall through which the termites could ascend. In the Sudan timber was scarce, and up till quite recently the entire requirements for building construction had been imported, so that the elimination of timber from buildings had not led to increased initial costs; in fact, in some cases a saving on original costs had been effected, and definite savings on maintenance costs had resulted. The disadvantage of creosote and of proprietary by-products was that an oil paint finish as required in first-class work could not be given until the creosote had dried off the surface, which had then to be treated with aluminium paint or some other sealing coat to prevent subsequent discoloration of the oil paint by the creosote. The only proprietary preservative not possessing that disadvantage that had been tried out with success as a proof against termites was "Cuprinol," of which extended use was now being made.

Paper No. 5003.[1]

"The Open-Frame Girder."

By Edward Hugh Bateman, M.A., B.Sc., Assoc. M. Inst. C.E.

Correspondence.

Mr. Beaufoy. Mr. L. A. Beaufoy observed that the application of the strain-energy method of stress-analysis to the solution of open-frame girders, or Vierendeel trusses, was of great interest at the present time, as more and more trusses of that type were now being erected. That was largely the result of the introduction into structural steelwork practice of welding, which had made available a very satisfactory medium for the fabrication of rigid frames without diagonals, and had given great impetus to their construction.

[1] p. 67 (November).

It might perhaps be useful to summarize some of the limitations of the analyses presented by the Author, which appeared to be :— Mr. Beaufoy.

1. That the depths of members were ignored ;
2. That chords were assumed to be parallel ;
3. That chords were assumed to have the same stiffness ;
4. That all vertical post members were assumed to have the same stiffness ;
5. That all members were assumed to have a uniform moment of inertia ;
6. That no account was taken of gussets at the joints.

Those characteristics were not, of course, realized in practical cases of Vierendeel trusses, but although that was so, the strain-energy method could still be relied upon to give a valuable first solution, and the Author had shown how the method might be applied when chords were not parallel or of equal stiffness. The fact remained, however, that in girders of the open-frame type strong gussets were frequently used, whilst cases did arise where members were stiffened locally or where the vertical posts had different stiffnesses, so that there was certain to be a redistribution of stresses due to those causes.

Account could be taken of all such factors in the deformeter method of stress-analysis, in which a two-dimensional model of the girder was subjected to test. The model was accurately proportioned to reproduce the stiffness-characteristics of the prototype, and was constrained at supports in a similar manner. To determine the bending moment at any particular section, the model was cut at that section, and the cut ends were twisted relatively to one another by an instrument which imposed a known amount of twist. The whole model, which was supported on a floating bearing, deformed and took up a new position. The resulting displacements of the points on the model at which loads were carried in the prototype were then measured in the directions of the lines of action of those loads. The bending moment at the cut section could then be calculated on the basis of Maxwell's theorem of reciprocal deflections. It would be evident that, by suitably designing the model, allowance might be made for any of the variable factors mentioned above. Thus the model was well adapted for use after preliminary calculations had shown which were the critical sections in the girder.

As a matter of interest, he had analysed by model one of the cases solved by the Author in his Paper (p. 80), namely, the case where $N = 6$ and $s = \frac{1}{3}$. No gussets were assumed, but allowance was made for the depths of members (that, incidentally, would

Mr. Beaufoy. modify the value of s). The actual geometrical proportions used were :

Depth of chord $= 0{\cdot}092\ H$.
Depth of post $= 0{\cdot}1\ L$.
Ratio $H/L = 1{\cdot}40$.

The results were shown in Table XII, where the values of the bending moments had been expressed in the same way as in the Paper, and the Author's calculated values were also given to aid comparison.

TABLE XII.

$N = 6;\quad s = \frac{1}{3}$.

The figures in italics give the calculated values from Table III (p. 80).

Values of the chord bending-moments.

	$R = 1$	$R = 2$	$R = 3$	$R = 4$	$R = 5$	Sum
α_1	1·39	1·40	1·11	0·76	0·37	5·03
	1·4338	*1·5088*	*1·2195*	*0·8327*	*0·4198*	*5·4146*
β_1	1·81	1·08	0·71	0·47	0·23	4·30
	1·8995	*1·1579*	*0·7805*	*0·5006*	*0·2469*	*4·5854*
α_2	− 0·83	0·73	0·88	0·62	0·32	1·72
	− *0·9312*	*0·7017*	*0·8780*	*0·6642*	*0·3458*	*1·6585*
β_2	0·20	1·82	1·10	0·62	0·30	4·04
	0·2645	*1·9650*	*1·1220*	*0·6692*	*0·3208*	*4·3415*
α_3	− 0·44	− 1·27	0·32	0·47	0·27	− 0·65
	− *0·4919*	− *1·3686*	*0·2927*	*0·4906*	*0·2968*	− *0·7804*
β_3	− 0·19	− 0·03	1·64	0·79	0·34	2·55
	− *0·1748*	*0·0353*	*1·7073*	*0·8428*	*0·3698*	*2·7804*

Values of the post bending-moments.

	$R = 1$	$R = 2$	$R = 3$	$R = 4$	$R = 5$	Sum
α_1	1·39	1·40	1·11	0·76	0·37	5·03
	1·4338	*1·5088*	*1·2195*	*0·8327*	*0·4198*	*5·4146*
$\beta_1 + \alpha_2$	0·98	1·81	1·59	1·09	0·55	6·02
	0·9683	*1·8596*	*1·6585*	*1·1648*	*0·5927*	*6·2439*
$\beta_2 + \alpha_3$	− 0·24	0·55	1·42	1·09	0·57	3·39
	− *0·2274*	*0·5964*	*1·4146*	*1·1597*	*0·6177*	*3·5610*
$\beta_3 + \alpha_4$	− 0·53	− 0·82	0	0·82	0·53	0
	− *0·5446*	− *0·8075*	*0*	*0·8075*	*0·5446*	*0*

TABLE XIII.

$N = 6;\quad s = \frac{1}{3}$.

$\beta_1 + \alpha_2$	0·93	1·76	1·49	1·03	0·54	5·75

Mr. Beaufoy.

It would be seen that the effect of the depth of members alone was appreciable in the modifications which it made to the bending-moment distribution in the girder. That was seen to be true, even for the proportions used in that case. Perhaps more usually in actual girders the depths of members were proportionately even larger, and it was therefore to be expected that there would be correspondingly greater discrepancies between actual and calculated moments. Another model, having members of greater depths, was therefore later tested for $(B_2 + a_1)$, namely, the bending moment at the ends of the second vertical post. In that case, the geometrical proportions of the model were such that the depth of chord was 0·184 H and the depth of post was 0·2 L, gussets of radius 0·114 L being allowed for at the joints. The results were as given in Table XIII.

The model tests described above illustrated the effect of omitting from the calculations any consideration of gussets or of depths of members. Probably the effect due to the latter cause could be allowed for by suitably modifying the calculated stiffness-ratios.

The Author.

The AUTHOR replied that it was most interesting to have such excellent experimental confirmation of some of the calculations given in the Paper. The calculated values were on the whole slightly higher than the experimental values; that, as Mr. Beaufoy had pointed out, was due to the fact that the calculations were based on the theoretical centre-lines and that no modification had been made to allow for the depths of the members, apart from their relation to the stiffness values. When gussets were used in the model the divergence between the experimental and calculated results was greater, but if the calculated values of the moments at the joints were used to determine the moments at the critical section where gusset and member met, reduced values would be obtained which would agree more closely with the experimental figures.

Mr. Beaufoy had observed that in model experiments many factors could be taken into account, the inclusion of which would be impracticable in theoretical analysis. If Mr. Beaufoy intended to suggest that analytical methods could be dispensed with altogether, there were several considerations which should not be overlooked. In the first place, the question arose as to whether the girder of uniform section was a possible form of design. Uniformity, whenever possible, was an essential feature in engineering design. For example, in the case of a triangulated bridge-girder, a uniform panel-length was adopted to make floor-units interchangeable, and the depth of the girder was diminished near the abutments so that in a through bridge there was no very great variation in the maximum loads on each upper chord section, whilst that variation in depth also reduced

The Author. the inequalities in shear-load distribution in the web members. In the case of the open-frame girder the chord members carried the normal axial loads, which were greatest in the centre, and they also carried the shear loads, in the form of the bending moments referred to, which were greater near the ends of the girder and less near the centre.

Another factor which had to be considered was that analytical methods were of importance when they gave not merely numerical results but expressions involving, for example, the lengths, moments of inertia, numbers, and positions of the various members, so that the effects of variations in those quantities could be assessed. One of the main purposes of the Paper, however, was the estimation of possible limiting values for the points of inflexion in the members; if those could be determined within reasonable limits, exact computation whether by analytical or experimental methods would be unnecessary. The effect of relative stiffness on the position of the points of inflexion was set out in Table XI (p. 92), and it was pointed out that in the case of a ten-panel girder fully loaded the points of inflexion in the three end panels, where the bending moments were greatest, were located close to the mid-points of the members, the divergence being not more than about 10 per cent. of the panel length in the case where the web members were of the same stiffness as the chords. In conclusion, a recent observation by Professor Hardy Cross [1] might be quoted: "The analysis precedes and dictates the design; after design no analysis is needed."

[1] "The Relation of Analysis to Structural Design." Proc. Am. Soc. C.E., vol. 61 (1935), p. 1119.

Paper No. 5024.[2]

"Earth-Pressure on Flexible Walls."

By Jens Peter Rudolf Nielsen Stroyer, M. Inst. C.E.

Correspondence.

Mr. Lee. Mr. D. H. Lee observed that it was always easy to criticize earth-pressure experiments, on account of the great difficulty in obtaining conditions in the tests which removed the many sources of error in the results. In the Author's experiments pressures and moments

[2] p. 94 (November).

had been obtained on one face of a box, the sides adjacent to that tested having been themselves not stiff enough to be without deflection comparable to that which had been obtained by the thicker test-plates. Mr. Lee.

It seemed reasonable to suppose that friction on the side walls had induced side support. Thus for a long wall the true horizontal pressures would be greater than those recorded, and the value for the reduction-factor, which was apparently slightly on the low side when taken as $r=2f/(1+f^2)$, might in fact require raising also to allow for the side support reducing the effective volume of material exerting pressure on the plate. Although lateral arching might not be great at the end of a slip it would appear to be discernible in *Figs. 24* (A) and (B), p. 139. Friction on the side walls causing lateral arching would be a function of grain-surface state rather than grain-shape, but the internal friction for the dry materials used was, generally speaking, dependent on the ratio of the conjugate diameters of the grains and the variation in size as well as on the surface condition. That might be the explanation of the greater slides in the case of linseed after the grains had been roughened by continued abrasion, and similarly with the pea gravel before the surface polishing had taken place ; in both cases the slides had been caused by a break-down of part of the lateral arch.

The reduction-factors proposed might appear higher than was expected, but the tests had been on materials apparently nearly devoid of cohesion, while the materials behind sheet walls examined by Dr. Ehlers and referred to in Mr. Stroyer's book,[1] might possibly have had, in general, sufficient cohesion to have exerted less lateral pressure and thus to have exhibited the equivalent of a lower moment reduction-factor. As the upper limit for combined cohesion and internal friction, Mr. Leys [2] had suggested a value of $k=1{\cdot}6$ ton per square foot at an angle of internal friction of about 17 degrees, which properties he had inferred for a mixture of earth and stones, whilst Mr. Bell [3] had found nearly the same values for a very stiff boulder clay. It seemed certain that materials of those types would exert fairly permanently both reduced moments and reactions on a sheet wall, and the earlier supposition that they usually exerted reduced moments, although seemingly without cause, might thus be explained. It was thus no matter for great concern that the Author

[1] R. Stroyer, " Concrete Structures in Marine Work," p. 23. London, 1934.

[2] H. H. Leys, " The Surface of the Earth as a Material of Construction," Journal Inst. Struct. E., vol. xii (1934), pp. 198 and 343.

[3] A. L. Bell, " The Lateral Pressure and Resistance of Clay, and the Supporting Power of Clay Foundations," Minutes of Proceedings Inst. C.E., vol. cxcix (1914–15), p. 233.

Mr. Lee.

recorded values for the reduction-factor higher than might have been expected, seeing that the effects of cohesion could hardly have existed in the materials used, while to have also used cohesive materials would have been to introduce many complications.

With regard to the permanency of the state of flex, it seemed possible that work supporting railway-tracks would be an instance where the flux state might easily be reached, particularly in the case of sheet walls partly in water. The Author's opinion that passive resistance might also revert to the flux state was of great interest. Whilst Dr. Franzius [1] contended that the angle of internal friction was the same for immersed soils, it would appear that any passive resistance due to cohesion would be reduced by immersion (unlike dampness), and thus the Author's opinion in that case would appear to be a warning against using too low a factor of safety in the estimation of the passive resistance of the foot of a sheet wall subjected to vibration, such as was caused by railway traffic. The fact remained that much evidence was available to show that at ordinary depths the passive resistance of soils was, in general, greater than that obtained by Rankine's coefficient $\frac{1 + \sin \theta}{1 - \sin \theta}$, and the use of the reciprocals of Professor Jenkin's [2] coefficients of active pressure would seem justifiable in all cases where the soil was essentially granular in character and no vibration of magnitude occurred.

Professor von Terzaghi.

Professor K. von Terzaghi, of Vienna and Harvard University, remarked that he was greatly interested in the problem of "arching," which had engaged his attention for several years, and that he had himself carried out tests on rigid retaining walls.[3] There appeared to be the following probable sources of error in the Author's testing apparatus :—

(a) The assumption that the earth-pressure moments and their deflections were proportionate would be correct only if the deflection had no influence on the distribution of the lateral pressure over the back of the plate. In reality, that distribution changed with increasing deflection. However, the error due to that change was relatively insignificant.

(b) The influence of the friction between the side walls of the container and the backfill would affect the distribution of stresses within the fill.

[1] O. Franzius, *Discussion on* "Analysis of Sheet-Pile Bulkheads." Trans. Am. Soc. C.E., vol. 100 (1935), p. 772.

[2] C. F. Jenkin, "Earth Pressure Tables." Building Research Special Report No. 24. Published by H.M. Stationery Office. London, 1934.

[3] "Large Retaining-Wall Tests," *Engineering News-Record*, vol. 112 (1934), pp. 136, 259, 316, 403, 503.

Professor von Terzaghi.

(*c*) The supports A and B (*Fig. 4*, p. 105) yielded elastically during the filling of the box, approximately in direct proportion to the pressure on the supports. When the box had been filled ready for a flex test, the total pressure on A and B was equal to the sum of the lateral earth-pressure P and the balancing force W, or approximately equal to 1·8 P. During the flex test the force W was gradually reduced to zero, and the total pressure on the supports A and B decreased from 1·8 P to P, which decrease involved an advance of those supports towards the fill, of approximately half the original yield. According to tests which Professor Terzaghi had carried out 7 years ago at the Massachusetts Institute of Technology, the slightest advance of a lateral support towards the fill produced a substantial increase in the lateral pressure. Hence it seemed probable that the decrease of the greatest bending moment produced by the gradual elimination of the force W was associated with an increase of the lateral pressure P, without the experimenter being in a position to estimate that increase.

The Author.

The AUTHOR, in reply, observed that his tests definitely proved that the effect of a state of flux on a soil in the flex condition was that the pressure reverted to normal, both in the case of the wall flexing outwards, and in the case of the wall pressing on the soil, as with passive earth-pressure. Mr. Lee was therefore striking the right note in advocating caution when estimating the passive resistance wherever there was danger of strong vibration, likely to induce a state of flux. The passive resistance given by Rankine's formula was, as Mr. Lee pointed out, on the safe side, and values more in accordance with actual facts might be obtained either from Professor Jenkin's figures or from Professor Max Möller's curves.[1] In reply to Professor Terzaghi's comment (*a*), it should be noted that even with two so widely different loadings, and such varying moment-curves, as those produced by the water load and by the earth-pressure triangle, yet the difference in maximum moments for the same deflection was quite small; therefore with loadings so much more similar, and moment-curves still more so, as those produced by earth-pressures, even with greatly varying distribution, the difference in maximum moments would surely be very small indeed.

With regard to the effect of the friction on the sides of the container, mentioned by Professor Terzaghi (*b*) and also by Mr. Lee, that friction was already fully mobilized when the flex test began,

[1] R. Stroyer, "Concrete Structures in Marine Work," p. 29. London, 1934.

The Author.

as the elastic supports had already receded under the influence of P and W. It was therefore to be expected that both the initial balanced value, and also the final flex value, would be obtained subject to the full friction. As the object of the tests was to determine, not the absolute values, but the relation between the initial and the final value, it would probably be agreed that for that purpose the effect of the friction on both might be neglected.

The effect of the rebound of the supports, discussed by Professor Terzaghi under (c), had received due consideration by the Author, and he submitted that the error introduced thereby would cancel out because of the peculiar conditions prevailing during the flex test. While the supports were moving in, the middle of the plate was moving out on its own account, and at a rate many times greater. It would appear that there was an essential difference between a quiescent soil where the supports were being pushed in, and a soil where the particles were all moving due to other causes. The resistance to the inward movement of the supports would therefore appear to be non-existent, or practically so, during that particular phase of the test, as was borne out by records of the support movement, which indicated that the inward movement of the supports had been performed without any restraint, presumably because the rebound had taken place in a material alive with movement, and that consequently no extra strain had been put upon the deflecting plate. That conclusion was also confirmed by the "free wall" tests (where the rebound phenomena did not occur) which gave the same results as the flex tests. The measurements of the support-movements were carried out only with a view to determine the error in deflection introduced thereby, and the support records gave the combined movement of the two supports at a point located at the same height as the point B on the plate, where the deflection was measured.

Professor von Terzaghi.

Professor VON TERZAGHI, in a further contribution, agreed that the sources of error discussed above would probably have no appreciable influence on the test results, but observed that separate records of the top and the bottom supports would have given much valuable information on the vital question of distribution of pressure on the back of the wall. Referring to a recent article on the theory of arching,[1] he pointed out that there was a great similarity between the problems discussed therein and the flex phenomena investigated by the Author. When the upper strata of a fill suffered incomplete lateral expansion, a pressure-distribution resulted which was totally

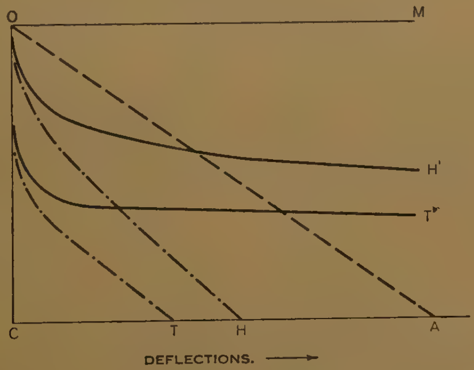
[1] K. Terzaghi, "A Fundamental Fallacy in Earth Pressure Computations." Journal of the Boston Society of Civil Engineers, vol. xxiii (1936), p. 71.

different from the generally-accepted hydrostatic triangle, and was characterized by a considerable increase in the top pressure associated with a corresponding decrease in the bottom pressure. That effect was observable with rigid walls subject to small movements, having been demonstrated by his tests,[1] and the redistribution would be even more pronounced with flexible walls, where the top support was restrained and the top layers prevented from attaining the lateral expansion necessary for hydrostatic distribution. Separate records of the two supports during flexing would have shown the upper reaction to bear a much greater proportion of the total pressure than the generally-assumed one-third.

Professor von Terzaghi.

Professor Terzaghi would suggest the following explanation of the influence of wall-thickness on the lag, an influence which had not been accounted for in the Author's Paper. Assuming that the ratio

Fig. 25.



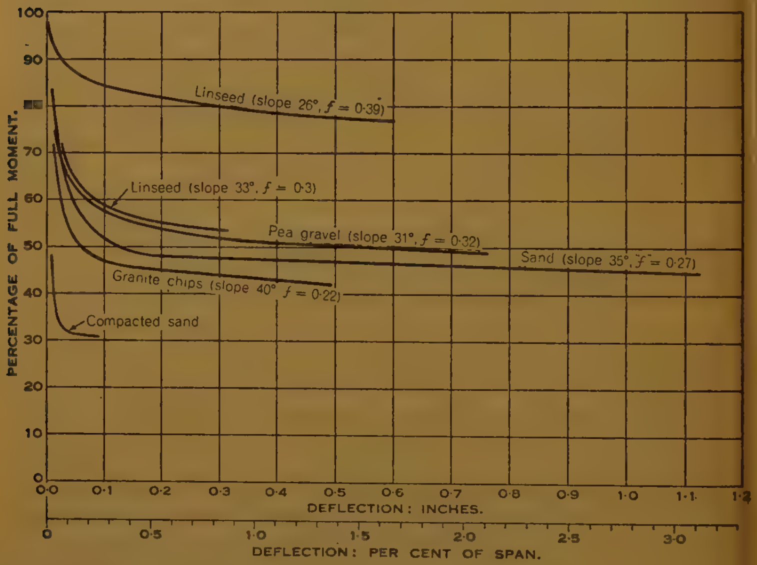
between the bending moments and their respective deflections was constant, a moment-curve could be plotted from the deflection-record, and would give the value of the moment on the plate at any point during the deflection, from zero at the beginning of the test to the final deflection at the end of the test. The two chain-dotted lines OT and OH (*Fig. 25*) represented the deflection-records for a thin and heavy plate respectively. The line OA indicated the check line (for full earth-pressure), the deflections being represented as abscissæ along the line CA. The lags for the thin and the heavy plate were represented by TA and HA respectively. The corresponding moment-curves were shown as OT′ and OH′, the full moment being indicated by the line OM. Now, although the two moment-curves appeared to be quite different, they were actually identical when referred to the same scale, it being remembered that the full

[1] *Loc. cit.*

Professor von Terzaghi.

earth-pressure deflection CA was many times greater with the thin plate than with the heavy plate. The straight part of the deflection record was not strictly parallel to the check line OA in the case of the heavy plate, although with the thin plate it was practically so.) Therefore the whole of the moment-curve OH′, when reduced to the same scale as that of OT′, lay on the first curved portion of the latter, and only the thin plate had a deflection large enough to let its moment line OT′ emerge from the curve to the straight portion, which was practically horizontal, so that the reduced moment remained nearly constant for any further deflection. In other words, it required a certain minimum deflection to reduce the moment from the full

Fig. 26.



value CO to the flex value AT′, and the heaviest plates did not deflect sufficiently to attain that reduction. That minimum deflection for sand appeared to be about ½ per cent. of the plate span (36 inches). The plate thickness, *per se*, had therefore no bearing upon the flex phenomena, except inasmuch as the deflection had to be sufficient if the full reduction were to develop. From tests which he had carried out on stiff walls he felt confident that that required minimum of ½ per cent. of the span would be still smaller if the fill material were compacted as it was brought in behind the wall; he understood, however, that no such tests had been carried out by the Author.

In conclusion, he expressed his interest in the tests carried out to ascertain the stability of the flex condition, and considered it highly

significant that even such violent disturbances as those produced by the rope test (*Fig. 13*, p. 119) were insufficient to destroy the flex condition. At the same time it was important to bear in mind that vibrations, especially with granular materials, tended to produce a state of flux, and that should be taken into consideration in estimating the flex reduction. Professor von Terzaghi.

The AUTHOR observed that, following the lines indicated by Professor Terzaghi, he had prepared a set of moment-curves (*Fig. 26*) for the different materials tested, with the exception of the Kentish Rag, which was not a truly granular material. The curves presented a uniform appearance and showed the influence of the liquidity-factor on the flex reduction. The Author.

Although the Paper did not mention any tests with compacted material, he had carried out several such tests, and the results were exactly as anticipated by Professor Terzaghi, the lag being much more pronounced, and the deflection required to produce it being only about 0·1 per cent. of the span. The thin-line curve in *Fig. 26* showed a typical sand test where compacting was carried out to the extent of raising the balancing pressure from 17 inches of water to 24 inches of water.

Paper No. 5007.[1]

"Vizagapatam Harbour."

By WILFRID CRACROFT ASH, B.Sc. (Eng.), and OSCAR BRANCH RATTENBURY, B.Sc. (Eng.), MM. Inst. C.E.

Correspondence.

Mr. G. P. ALEXANDER, of Madras, having in view the comprehensive nature of the Paper, wished to confine his remarks to littoral drift and its application to the Madras seaboard. A most interesting and lucid description of coastal sand-travel, as found near Madras harbour, had been given by Sir Francis Spring[2] in 1912; the problem still existed there, but not in so acute a form as at Vizagapatam, where apparently dredging would always be necessary to keep the entrance-channel open to traffic. There now appeared to be some uniformity of opinion as to the principal agency promoting Mr. Alexander.

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[1] p. 235 (December).

[2] "Coastal Sand-Travel near Madras Harbour," Minutes of Proceedings Inst. C.E., vol. cxciv (1912–13), p. 153.

Mr. Alexander. sand-drift; the primary cause was undoubtedly wave-action, which was confined to a narrow belt close in-shore, where the waves were of a translatory type. A secondary agency inducing sand-travel (at any rate near Madras), was undoubtedly the combined action of the littoral and surf currents which, although feeble, attained sufficient velocity during the south-west monsoon to carry the finer particles of sand into "dead" water, thus forming deposits. From the remarks made by the Authors and from his own experience at Madras, it could safely be assumed that there were no tidal currents of measurable magnitude sufficient to promote sand-travel along the Madras seaboard.

There was some diversity of opinion about the most effective way of counteracting sand-travel, but local conditions would always play an important part in that complex subject. At Vizagapatam, for instance, Mr. Ash had decided that the best way to deal with the problem would be to reduce the agency by which sand was moved, and to create a "trap," protected from the worst weather, where the dredger could lie with reasonable comfort and remove the seasonal accumulation of sand. At Madras, on the other hand, it had been decided to throw out a shore-connected groyne to retard the sand-drift past the harbour, which, if not arrested, might eventually threaten the approaches to the Port. Reviewing the results after 10 years, Mr. Alexander considered that the experiment had only been partially successful; most of the wave-driven beach-sand had been confined south of the "trap," but the combined action of the surf and littoral currents had carried a considerable amount of the finer particles of sand around the end of the sand-trap, where a deposit had formed. The deposit was small and unimportant at the present moment, but it would undoubtedly become a major problem when it increased sufficiently to come under the influence of the waves of the south-west monsoon.

On account of his experience at Madras, he considered that the construction of the island breakwater was the better method to apply at Vizagapatam. He would be glad if the Authors would say how the island breakwater had affected the littoral or surf currents in the vicinity of the entrance, including the gap between the Dolphin's Nose and the end of the island breakwater. He would also like to know whether the depth of water between the Dolphin's Nose and the island breakwater had increased or decreased since the construction of the breakwater.

He would be glad if Mr. Rattenbury would clarify the explanation given (p. 254) to account for the variation between the direction of the currents during north-east and south-west monsoons. After stating that the tidal currents in the bay were small and unimportant,

Mr. Rattenbury went on to say that, during the south-west monsoon, the ebb set up the coast at the rate of about 1 knot, while during the north-east monsoon, the alongshore current was down the coast, and that he attributed those variations to wave-action. Mr. Alexander would like him to re-affirm that it was the "ebb" which set up the coast, and he would suggest that the currents were not due to wave-action but to the prevailing monsoon-winds. Mr. Alexander.

Mr. J. N. D. La Touche drew attention to the remarks about manganese and mild-steel cutter blades (p. 272), and observed that it was noteworthy that the Indian *beldars* (navvies) preferred the soft native iron for their *phowras*, or excavating hoes, to the cast steel of those sent out from England; they said that the soft iron both cut better, and lasted longer, than the steel. Mr. La Touche.

Mr. James Mitchell observed that the decision to make a land-locked harbour at Vizagapatam, instead of an offshore one, was undoubtedly wise, but it was somewhat surprising to find provision being made for scouring-basins. Such basins had a limited value where the depth aimed at was only a little below low-water level, but with the depths required for modern vessels they had little or no value, and the large area which they necessitated could generally be used to much better purpose. Mr. Mitchell.

The ideas of the island-breakwater and the sand-trap were well conceived, as was also that of the use of steamships as a nucleus for the breakwater. In no other way, probably, could the breakwater have been so quickly and so certainly constructed. The breaking of the backs of the vessels was a thing likely to occur, but was of comparatively little importance. With reference to the statement on p. 287 that, in sinking the "Janus," "the ship moved bodily over about 15 feet as she was grounding," it might be suggested that in such works, and in the sinking of caissons in the open sea (where it was of the utmost importance that sinking should take place as quickly as possible after the structure had been got into position), a much larger area of scuttling-valves should be provided than was usually the case. The valves, being intended for only a very temporary use, might be simple and inexpensive, while in the case of a ship, their number might be reduced by burning holes in the bulkheads, so as to put the various compartments into such communication with each other as might be thought advisable. The sand-trap was an old and useful device in dredging work, and at the harbour of Aberdeen it had been used for well over half a century with excellent results.

The location of the breakwater was a very suitable subject for investigation by means of models, and attention had been drawn in the Paper to the necessity for exercising a considerable amount

Mr. Mitchell. of caution in dealing with the results of such experiments, and to the advisability of regarding them as being rather qualitative than quantitative in character. Perhaps Mr. Ash would state his grounds for the statement on p. 246 that "the reaction between the water and the wet sand was that between a lighter and a heavier fluid, not that between a fluid and a granular mass." It was true that, in the case of the sand, each grain was coated with a film of water, which moved with it, just as in the case of a larger stone, and that that film would have an enormously greater influence on the movement of the small particle than on that of the larger one. That indicated one of the great difficulties in securing similarity of conditions in such models, but it did not appear probable that it would be helpful in interpreting results to regard a mass of wet sand as being a heavy fluid. With regard to the model generally, it might be suggested that its north-east wall was too near to the channel, and to the island-breakwater, to give a complete reproduction of actual conditions.

Reference was made (particularly on pp. 243 and 256) to the obliquity of waves breaking on the beach, and to the influence of such waves in causing sand-travel along a strip of the beach from 400 to 600 feet wide. Attention was also directed, both on p. 243 and in other places, to the feebleness of the sea-currents. Long-continued observation of the waves breaking on a beach during storms showed that their direction was unaffected by the direction of the waves in the offing. As the waves approached the land, their direction was dictated more and more by the contours of the sea-bed. That was particularly the case with a ground-swell, which, to use a seaman's phrase, began to "smell the bottom" in much deeper water than in the case of what might be called a "wind-wave," with its much shallower zone of influence. With regard to the strength of the currents, there was, during a gale, a pronounced heaping-up of the water in the direction towards which the wind blew, and that caused a corresponding current in the opposite direction and at a lower level. To those currents would in certain circumstances be added the currents similarly induced by the heaping-up due to the tides.

Mr. Ash. Mr. Ash, in reply, doubted whether Mr. Alexander was quite correct in saying that the sand-travel at Madras was in a less acute form than that at Vizagapatam. From enquiries made on the spot and from published statistics, it appeared that the average amount of sand passing a given point on the beach at Madras in the course of a year was of the order of 1,000,000 tons, as at Vizagapatam. Mr. Ash believed that that figure would, in the nature of things, be fairly constant all along the east coast of India.

Mr. Ash.

The means of combating the sand-travel which could be adopted at Madras were, on account of the local configuration, impracticable at Vizagapatam. The trouble at Madras to which Mr. Alexander drew attention, namely, that of the travel of the finer particles at a considerable distance from the shore, had inevitably to be faced, whether the means of defence were a sand trap or a " sand screen," as the shore-connected groyne at Madras was locally termed. The travel of the finer particles could, in rough weather, be clearly seen at Vizagapatam, from the top of the Dolphin's Nose. A small quantity was deposited in the channel, but the volume was such that it could be dealt with in a few days' dredging during the calm season.

Regarding the local effect of the island breakwater at Vizagapatam upon the littoral current, a strengthening of the current had been observed across the channel, near the Dutch Fort, during rough weather and at low water. That was not unexpected, having been observed on the working model. The waves of translation, passing along the coast to the south of the breakwater, caused a " heaping-up " of the water in the little bay, and the passage of that water was restricted by the breakwater, thus causing an increase of velocity. There had, up to the date of Mr. Ash's latest information, been some shoaling at the passage between the island breakwater and the Dolphin's Nose. The increase of current strength, combined with the wave-action, would, it was thought, set a limit to the shoaling tendency in that area, but if it were found not to do so, the present dredging area would have to be extended to the south. The velocity of the current under the stated weather and tide conditions had, in the early stages, been high enough to cause some anxiety to the pilots.

He quite agreed with Mr. Mitchell regarding the scouring basins. That idea had never, in his opinion, had in it a germ of utility. Regarding the suggestion that much larger scuttling valves would have been more effective, it was pointed out that two had been provided in each hold. The ships, whilst being scuttled, had to be allowed to " range " under the action of the swell, which was appreciable, even on the calmest day. Whether the speed of immersion were high or low, there would be a point at which the sandy bottom would prevent further ranging. The travel would be much the same in either case, and it was largely a matter of chance just where the hull came to rest. Control was possible only within certain limits, and it sufficed for the purposes in view to achieve the degree of accuracy which was actually obtained.

He believed that he had grounds for regarding the action of the wet sand as that of a heavy fluid. It appeared to be a characteristic of a fluid mass, made up of layers of different densities, that motion

Mr. Ash.

in an upper layer caused ripples in the layer below. Wind ripples on a beach gave one instance, and the ripples on tops of horizontal beds of clouds, when a light breeze sprang up in the air above, afforded another quite interesting one. The sandy bed of the working model was rippled as soon as wave-action was started. The rate of travel of the ripples was studied and compared with that of the corresponding ripples on the sea bed. That ripple action would, incidentally, be a subsidiary cause of sand-travel. However, the sand in the model represented, to scale, not sand but sharp-edged stones of considerable size, the behaviour of which might, under the wave-action of the sea, be expected to differ from that of sand; yet the sand in the model did behave substantially as did the sand in the sea. The explanation put forward was that wet sand could, for such purposes, be regarded as a heavy liquid.

His observations endorsed all that Mr. Mitchell said regarding the direction of wave-action and the agencies affecting shore currents. The direction of the wave-action during the south-west monsoon was, at a distance of 3 or 4 miles from the beach at Vizagapatam, almost at right angles to the wave-action which had to be considered in connection with the entrance to the harbour. The speed of the shore current was definitely related to the state of the sea, and a strengthening of it was clearly observable when a heavy swell occurred in the absence of wind.

Mr. Rattenbury.

Mr. Rattenbury, in reply, observed that the lie of the coast south of the breakwater at Vizagapatam was very different from that existing at Madras. There were miles of low-lying sandy beach at Madras which had extended seaward by accumulation of sand brought to rest there as the trap breakwater had been extended seaward from the harbour-enclosing breakwaters. At Vizagapatam there was the steep face of the Dolphin's Nose, on which sand did not lie. It was true that to the south of that point there was a sandy bay, but it was unlikely that any practicable length of spur built from the coast near the entrance-channel would suffice to arrest the flow of sand round its end in the efficient manner which had been so successful at Madras.

The opening between the end of the breakwater and the Dolphin's Nose had been reduced considerably in water-area since the completion of the breakwater. The depth near the breakwater, however, had been maintained, but near the Dolphin's Nose the depth was much less. The probability was that the depth near the breakwater would have been increased by scouring action to compensate for that, but as the sea-bottom was now protected by boulders near the end of the breakwater the waves had not been able to dig out the bed.

There was a tendency for a curved ridge of sand to form inside the opening right round on to the face of the breakwater, but it was not very pronounced at present. Mr. Rattenbury.

At ebb, and down to low water during bad weather in the south-west monsoon, an awkward surface cross-current set in right across the entrance-channel at about 3,800 E, which made pilotage of light ships up the channel a matter for care. It probably always existed, but had been intensified by the construction of the breakwater and the constricting action of the gap on the water passing through.

Inasmuch as the direction of the wave-action was caused by the direction of the prevailing winds, the currents up and down the coast might be said to be caused by the winds. The ebb naturally set to the north, but the current was a slight one. In the south-west monsoon the wave-current and ebb coincided in direction, but in the north-west monsoon they were contrary in action. The wind- or wave-current was stronger than the ebb, so that contrary currents arose in different seasons of the year. Probably during the north-east monsoon the southward current was stronger during the flow than during the ebb, but he was not sure of that.

Paper No. 5031.[1]

"The Energy-Output of the Coal-Miner."

By Professor Kenneth Neville Moss, O.B.E., M.Sc., Assoc. M. Inst. C.E.

Correspondence.

Mr. E. C. Homersham agreed with the Author that miners required a proper supply of nourishing food. He pointed out that the pit-head facilities at most collieries in Great Britain left much to be desired, and he would advocate the putting into force of regulations ensuring the provision of satisfactory facilities and housing accommodation; such regulations would greatly improve the lot of the miner and would increase his efficiency. About 35 years ago the South African Government had imposed such regulations on the Rand mine-owners. Objections had been raised that the mining industry would be put to additional expense, but no mine had closed down as a result of the regulations. He wished to point Mr. Homersham.

[1] p. 354 (January).

Mr. Homersham.

out, however, that regulations were useless unless they were enforced. The South African Government had met that objection by inserting a clause in the regulations to the effect that if, through the neglect of the powers controlling the mine, the manager was hindered in obeying the regulations, the Chairman, or acting Chairman, became responsible and liable to punishment. The prosecution of a Chairman had, however, never been necessary.

Sir John Orr.

Sir JOHN B. ORR observed that he was especially interested in the Paper because he had been in the pits in Ayrshire and had watched the miners at work. Professor Moss was the first to determine the energy-output under actual working conditions; from results obtained in the last year of the war on soldiers engaged in various exercises, and from his recollection of the difficult physical conditions under which miners worked, involving the simultaneous use of groups of muscles of limbs and trunk, the figures given corresponded with what might have been anticipated. Studies of that kind, where the calorie requirements were determined under actual working conditions, were of especial interest at the present time, when minimum dietary requirements were under consideration. Theoretical calculations based on limited data would have to give way to direct observations under actual conditions, such as those made by Professor Moss. There was not the slightest doubt that the food requirements of the miner would have to be reconsidered in the light of Professor Moss's results, and it would be in the interest of practical dietetics if more observations of that kind could be made.

The Author.

The AUTHOR observed that the correspondence on his Paper did not call for any reply.

Paper No. 4977.[1]

"The Treatment of Mud-Runs in Bolivia."

By STEPHEN WILLIAM FRANCIS MORUM, B.Sc. (Eng.), Assoc. M. Inst. C.E.

Correspondence.

Mr. Blencowe.

Mr. SIDNEY BLENCOWE observed that the Author emphasized the damage that might, and did, result from the action of mud-runs; such runs were common throughout recent geological formations

[1] p. 426 (January).

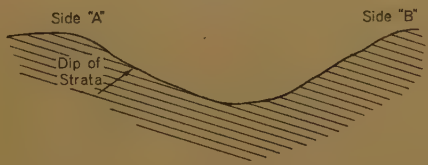
Mr. Blencowe.

and were especially prevalent in South America. In Argentina the route of the Transandine Railway between Mendoza and Cuevos was particularly susceptible to disasters from mud-runs, and at Santos, Brazil, a considerable number of houses had been engulfed by a flow of between 1 and 2 metres in depth. He concluded that those mud-runs were characteristic of those in Bolivia, of which he had no first-hand knowledge, although he had visited the region where the runs occurred.

The trouble caused on railways was largely due to faulty location, and he suggested that the dip of the strata was all-important to railway location where mud-runs were prevalent. Whether on the mountain side or within the valley the dip was generally wholly positive or wholly negative in a district, as shown in *Fig. 13.*

A railway, together with the township dependent upon it, should be located on the side that was immune from the run, namely, side "B." Unfortunately, all too often that was not taken into account.

Fig. 13.



Mr. Lavis.

Mr. Fred Lavis, of New York, had read the Paper with much interest, as he had had to deal, some years ago, with similar problems in connection with the location and design of the railway line between Atocha and Tupiza in Bolivia. At that time he had studied the problems which had then already begun to develop on the existing line between Oruro and Cochabamba, and those in connection with the proposed Potosi—Sucre line.

On account of the unstable character of the geological formations in the Andean region of South America, as well as in the northern extension of that mountain range through Central America, the details of location of any railway or highway route in those regions required the most careful study. The Gaillard (formerly named the Culebra) cut at Panama was perhaps the most widely-known example of the difficulties encountered in deep rock cuttings, but those conditions were prevalent on many railways. That made it of doubtful expediency to develop a line with heavy cuttings in order to avoid such difficulties as the *mazamorras* of Bolivia, or the scour of embankments parallel to the torrential and "flashy" mountain rivers. All such cases required judgement not only as to the first cost of

Mr. Lavis. such lines, but also of the effect of the location on subsequent costs of maintenance.

The Author apparently criticized, although somewhat mildly, the locations of some parts of the railways of Bolivia in "convenient river-valleys," and implied that they might have been located elsewhere. In many places, however, the choice of route was limited by the tremendously mountainous country, where any lines which left the wide central valley (except the Antofagasta Railway) could not get over or through the surrounding mountains except through the river-valleys. Almost all the latter involved difficult problems similar to those described by the Author. The point to be emphasized, however, was that few, if any, of those problems could be solved by formulas or by any accurately-worked-out scientific approach. The Author's descriptions of some of the actual methods used in treating the mud-runs would be of great value. In those locations, however, each individual site had to be the subject of special study and of the application by the engineers of experience and judgement of such parts of, or variations of, those methods as good judgement and experience might dictate.

In the location of the Atocha-Tupiza line, following the Tupiza river with very steep and high mountainous slopes on both sides, Mr. Lavis's problem had been first to select the side of the river with fewest or smallest *mazamorras*, making crossings of the main stream from time to time to accomplish that result. He had then proposed to keep the line as far down on the slopes and as close to the river (but, naturally, above the high-water level) as was reasonably possible, building retaining walls at the bottoms of the embankment-slopes along the river rather than running the risks of heavy cuttings with the indicated imminent dangers of future slides. As for the *mazamorras* themselves, it had been expected to cross them either with steel bridges with reasonably long spans, with deck and through girders in multiple spans of perhaps 40 or 60 feet or, in some cases, with reinforced-concrete pile trestles.

Mr. Legget. Mr. R. F. Legget, of Montreal, considered that the Paper gave interesting descriptions of experimental works of an unusual nature, which were so dependent on local conditions that detailed discussion of the measures taken was difficult. He suggested, however, that the value of the Paper would be enhanced if even a brief general description of the local geological formation were to be given by the Author, especially if it could be accompanied by a typical geological section across one of the valleys described. Was it correct to assume that the object of the check-dams was to form a series of flat slopes as a stream-bed, which would have the effect of reducing the velocity of mud-runs and of other flows? Was it the intention

to add to the height of the check-dams from time to time, or would that be unnecessary? The reference on p. 431 to the abrasive power of the mud-run was interesting; could the Author amplify that brief note? Mr. Legget.

*** Owing to loss of papers in transit, the Author's reply will appear in the January, 1937, Journal (Vol. 4, 1936–7).—SEC. INST. C.E.

Paper No. 5029.[1]

"Reinforced-Concrete Chimney Towers at the Barton Power-Station."

By ARNOLD ATHERTON, B.Sc.

Correspondence.

Dr. R. H. EVANS observed that it was desirable to point out that the influence of a variable modular ratio on the calculated stresses in reinforced-concrete structures was not so drastic as the Author had indicated on p. 516. In the new Handbook[2] on the Code of Practice for reinforced concrete, the modular ratio recommended agreed with that deduced from the secant modulus of elasticity of the concrete after 1 day of creep under the permissible stress, the creep of concrete after 1 day being but a very small fraction of the total creep that would ultimately appear under the sustained stress in, say, 5 years. The reason for that was that few structures carried the full live load continuously for such long intervals as 1 day, and that although the concrete would creep under the full live load a portion of the creep would be ultimately recovered after the removal of the load. That was the well-known property of "elastic-after-working," "Weber-effect" or "*elastische nachwirkung*." Furthermore, it was still necessary to adopt a variable modular ratio even if the concrete were perfectly elastic and exhibited no creep. The modulus of elasticity of concrete depended on the richness of the mix, on the grading and quality of the aggregates, on the water/cement ratio, on the age at testing and on the method of curing, and a variable modular ratio was necessary in much the same way as the modular ratio to be used in the design of flitched beams depended on the elastic properties of the wood. Calculations in connection with reinforced-concrete beams showed that, excluding Dr. Evans.

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[1] p. 505 (January).

[2] W. L. Scott and W. H. Glanville, "Explanatory Handbook on the Code of Practice for Reinforced Concrete," pp. 17–19. London, 1934.

Dr. Evans. the assistance afforded by the concrete in tension, the shear stress and the stress in the tension reinforcement varied only slightly with an increase in the assumed value of the modular ratio. There was little change in the bond stress, whilst the maximum concrete compressive stress actually decreased with an increase of the modular ratio. If any compression reinforcement were provided the stress in the reinforcement was increased appreciably on account of the predominating effect of the increase in the value of the modular ratio. That also applied to reinforced-concrete columns. With regard to deflections, calculations showed that the deflection increased with an increase of the modular ratio, the percentage increase being dependent upon the percentage of reinforcement.

The temperature records in the newly-placed concrete were most valuable, and the Author was to be congratulated for taking the opportunity of measuring the temperature-rise in the foundations and in the columns as well as the vertical and horizontal strains. With regard to the strain measurements, however, there were a few points that called for comment. The first was in connection with any slight temperature-differences that would exist between the 1-inch gas barrel and the steel rod of the lateral strain-gauge. *Fig. 8* (p. 519) showed very clearly the rise in temperature developed in the newly-placed concrete during hydration, the maximum temperature in the centre of the columns having been from 40° to 50° C. Since the steel rod was subjected to a greater cooling effect, being surrounded by air and being more exposed at the ends, it was reasonable to believe that the 1-inch gas barrel, which was in direct contact with the concrete, would always be at a higher temperature than the steel rod. That difference would increase during the early stages of the hydration, more particularly during the first day or two. The influence of that temperature-difference was to show an apparent lateral expansion which amounted to approximately a strain of 12×10^{-6} per °C. difference in temperature between the gas barrel and the steel rod. Consequently, only a temperature-difference of 2° C. would have been necessary to make it impossible to make any definite conclusions from the recorded lateral strain measurements. Such a temperature-difference also offered a reasonable explanation for the excessive lateral expansion recorded in *Fig. 10*, which the Author, on p. 522, stated was far in excess of that which would be anticipated from the combined stresses. He would suggest, as a possible explanation of that result, that the average curing conditions across the column had approximated to water-cured conditions. Tests by Messrs. Davis, Davis and Hamilton [1] and by

[1] "Plastic Flow of Concrete under Sustained Stress," Proc. Am. Soc. Test. Mat., vol. 34 (Part II) (1934), p. 354.

other investigators showed, however, that the expansion of concrete, when either stored in air at 100 per cent. relative humidity or immersed in water, took place gradually over such intervals as from 2 to 3 years. Their experiments did not show a fairly sharp expansion during the first 30 days or so, followed afterwards by a slight shrinkage, as in the Author's lateral strain curve in *Fig. 10*. The vertical strain was naturally easier to record and did not call for such precise extensometers or gauges as had been found necessary in measuring lateral strains. Dr. Evans.

Finally, it would be of interest to know the method adopted by the Author for determining the instant the micrometer head made contact with the steel ball when carrying out the strain measurements. If that instant were left to a sense of touch, different observers would obtain slightly different results, and it seemed necessary to adopt the usual electrical method of reading those strains to $\frac{1}{10,000}$ inch, thus giving an accuracy of about 2 per cent. on the maximum lateral expansion recorded in *Fig. 10*.

The Author, in reply, wished to thank Mr. Evans for the many points of interest and valuable criticisms of the experimental work at Barton. The Author.

In describing the introduction of a variable modular ratio as drastic, the Author's intention was to emphasize that creep, together with other factors, was of such importance as to necessitate a new practical conception of the fixed modular ratio, the fundamental link in calculations dealing with steel and concrete.

In view of the interesting results obtained at Barton, further temperature and strain records were being taken in a large mass of reinforced concrete forming part of the foundation for a turbo-generator at the Stuart Street power-station of the Manchester Corporation Electricity Department. It had been possible to obtain parallel temperature-records, by means of thermometer-tubes and thermocouples, which had shown that there was a tendency for the thermometers to read from 0·5° to 1° C. low at peak temperatures and also to lag behind the thermocouples, probably owing to condensation in the tubes and to the circulation of air in withdrawing the thermometers. In the case of the strain-gauges it was not likely that that cooling effect was present to the same degree, as air-circulation in the tube was prevented by the rubber spacers and the end plugs. With the sealing plugs in position the end-conditions for cooling of both tube and gauge-rod were practically identical, and it was not likely that there would be a temperature-difference of more than 0·5° C. between tube and gauge-rod, even at peak temperatures. It had also to be remembered that that slight temperature-difference would only affect the strain readings during the first few

The Author. weeks after concreting, and would disappear as soon as stable temperature-conditions were reached.

As distinct from the laboratory tests referred to by Mr. Evans,[1] where the curing conditions were constant over a considerable period, the conditions at Barton were such that while the steel-faced shuttering was in position, during the critical early life of the concrete, there was practically no loss of moisture, whereas as soon as the shuttering was struck, air-curing of the outer skin and an outward movement of moisture from the core started. The complexity of the strains during such moisture-movements had been pointed out by Dr. W. H. Glanville.[2] It was particularly in an effort to obtain information on the varying strains during those moisture-movements that the further experimental work was being carried out, and it had been possible to place strain-gauges at various depths in the concrete. Those, together with a more complete temperature-record, should give information on the shrinkage-strains during drying-out.

With regard to the actual method of taking the strain-measurements, it was necessary in view of the heavy nature of the work near the gauges, such as stripping shuttering, that the first consideration should be simplicity and robustness, even at the expense of the refinement of accuracy which could undoubtedly have been obtained by the methods suggested by Mr. Evans. It should have been pointed out in the description of the micrometer that there was a small adjusting knob at the end of the handle which was fitted with a spring tension, so that when slip took place there was a constant-pressure contact between the micrometer and gauge-rod.

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[1] *Loc. cit.*

[2] Department of Scientific and Industrial Research; Building Research Technical Paper No. 11, "Shrinkage Stresses," p. 37. London, 1930.

NOTE: For Index, see end of Volume 3, 1935-36.